Uniform set, in good condition
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PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF

PHILADELPHIA

VOLUME XXIX

EDITED BY THE PUBLICATION COMMITTEE

PHILADELPHIA

THE ENGINEERS' CLUB OF PHILADELPHIA

1912

THE ENGINEERS' CLUB OF PHILADELPHIA

1317 Spruce Street

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THE ENGINEERS' CLUB

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PAPER NO. 1105.

FAILURE OF AUSTIN DAM.

J. W. LEDOUX.
(Active Member.)

Read October 21, 1911.

THE failure of the dam at Austin, Pennsylvania, on September 30, 1911, affords a sad but immensely valuable lesson to hydraulic engineers. It teaches that in building such structures the first requirement is the absolute safety to human life; the second, that it shall serve its purpose; third, that it shall cost a minimum. Apparently, in this case the ends attained were in reverse order with the last term negative.

It is a principle of humanity that the most valuable lessons are taught and firmly impressed by discovery of disastrous error. Some one has said that no engineer is safe until he has made some serious blunder.

The consequence of the Austin dam failure will probably result in making unduly expensive for the next few decades all similar structures.

The Johnstown flood taught the importance of the spillway for earth dams, while subsequent experiences in the Allegheny Mountains gave specific data which indicated that in small drainage areas of 1 to 10 square miles it is not unreasonable to provide for a flood flow of 400 cubic feet per second per square mile.

The design of a masonry dam, as far as its section is concerned, can be successfully executed by any technically trained boy just out of college. It is only necessary to be familiar with the simple principles of statics, the resolution of forces, and a few empirical rules. To resist overturning he makes the section such that the resultant of the water pressure and the weight of the assumed section of unit thickness will fall within that section at every point. If this condition is fulfilled, under the most severe conditions of exterior load that will ever take place, the dam will not overturn unless the masonry or rock crushes. To avoid this, as well as to provide for a factor of safety, the shape is made such that the resultant falls at all depths within the middle third of the section. In making this calculation it is considered conservative to allow for possible upward pressure. Under the worst conditions this might amount to half the hydrostatic pressure, but no one allows for more than a third, which is even then considered ultraconservative.

It is sometimes considered proper to calculate the safety of the structure against sliding, and for that purpose he assumes the entire horizontal pressure of the water resisted by the weight of the dam, less the assumed upward pressure, which net weight is multiplied by the coefficient of friction between masonry and rock, using about 0.7. In both cases a factor of safety of two is considered good practice. The effect of sliding, however, can be eliminated by carrying the structure down into the rock ledge a sufficient distance to effectually prevent sliding.

Theoretically, the top thickness may be zero, but when the effect of unequal strains, frost, and the possible blow from a log, or tree, or ice thrust is considered, 4 feet is none too much, and for a large dam 6 feet is better.

Now, when all these requirements are fulfilled, the pure mathematics portion of the work is done, but the real difficulties are yet to come.

The material upon which the dam is to be founded must be considered. If the foundation is not excavated deep enough the structure will fail, and if it is taken down too deep the cost will be prohibitive, and within these two extremes the engineer has abundant opportunity to tax his judgment to the utmost. The author remembers an excavation for a masonry dam in the South. The bottom looked good and solid, gneissic rock at a depth of about 15 feet, but a series of drill holes revealed a large cavern at a depth of only a few feet below the excavated surface.

Again, if the rock is fairly solid but pervious to water, shall the entire structure be carried down to full depth or only a cut-off wall under the up-stream toe? If the rock is found compact and impervious to water, but too soft to resist the erosive effects of falling water below the down-stream toe, how shall this be treated? But these are only one or two of the innumerable questions that tax the judgment of the most experienced engineers during the construction of an important dam, when it is necessary to save every dollar possible without taking chances.

In constructing an important dam in the Allegheny Mountains, where the cracked and distorted rock structure presented the greatest difficulties, the following methods were pursued: The excavation was carried down the full width of the assumed bottom section of the dam to a depth which indicated that the rock base was amply solid and hard to afford sufficient bearing power. A narrow trench some 6 feet wide, having its upper face in a plane with the up-stream face of the dam, was then excavated. In two of the most important cases this trench was excavated by means of a channelling machine. The full section was carried down some 30 feet, and the cut-off trench a maximum of 30 feet farther, until the bottom appeared to be impervious to water. In order to test this and insure its water-tightness, hand drill holes were sunk in the bottom 15 feet deeper and spaced about 8 feet apart. A special stuffing-box device was inserted into each one of the holes, commencing, say, near the center, and water was pumped into these holes, under as high pressure as possible, using a hand pump for the purpose. Pressures usually ran from 20 to 50 pounds per square inch. If the rock was at all porous water would appear in the adjacent holes. While pumping, Portland cement was stirred into the barrel from which the pump obtained its suction, until the cement water appeared in the adjacent holes. More and more cement was stirred in until the proportion of cement to water by weight was about one to two. Finally, pumping became more difficult until it was impossible to pump the slightest amount of grout into the hole, and the pressure increased to the limits of the pump, say 100 pounds per square inch, or more.

The same process was continued for the alternate hole, and after all the holes were treated in this way the intermediate holes were grouted in the same manner. This is a very effective method, as was demonstrated in a large number of cases.

The construction of the dam was then begun, and after the work


B
C
E
F
J
Looking Down Stream.

FIG. 1.

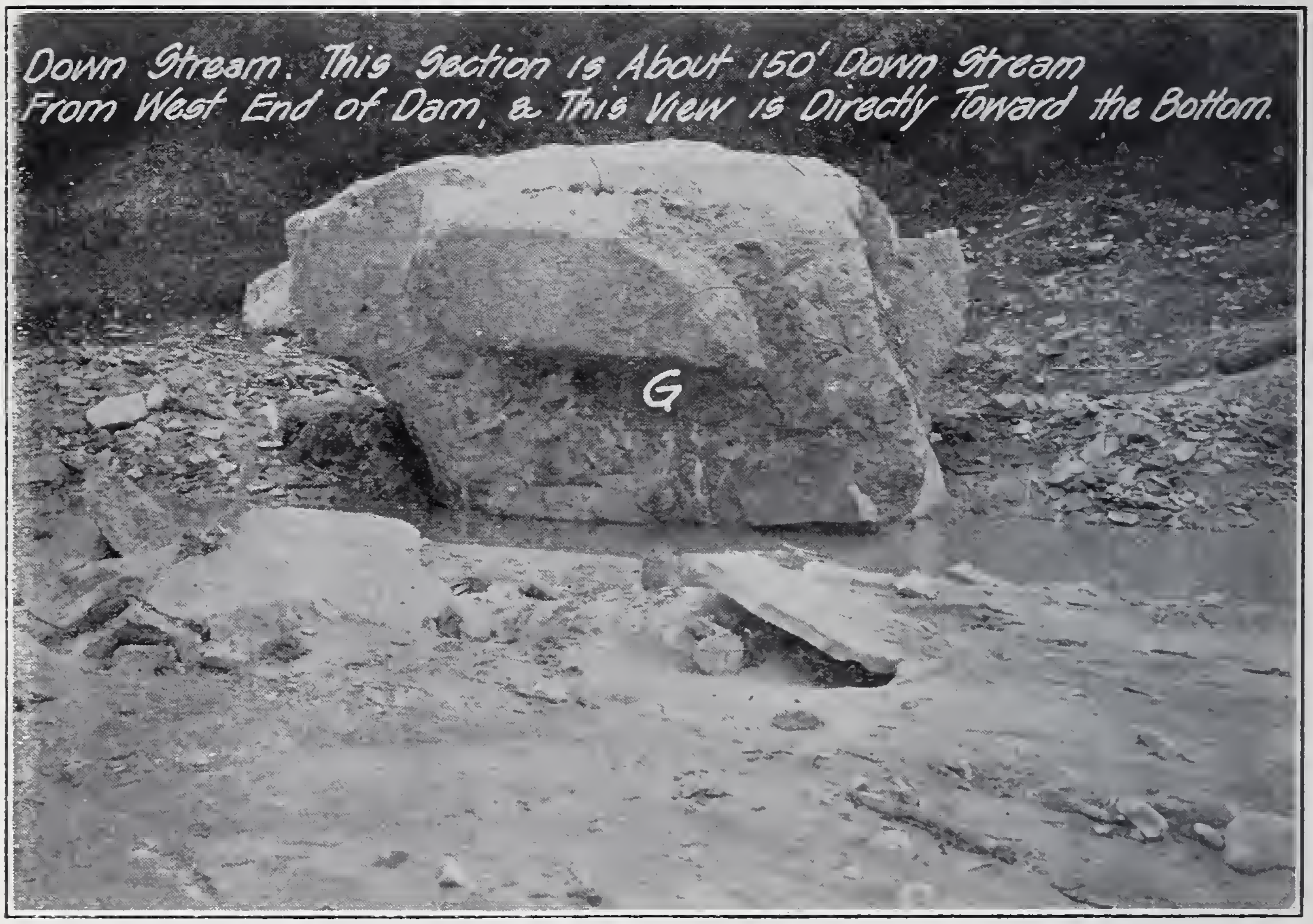
Down Stream. This Section is About 150' Down Stream
From West End of Dam, & This View is Directly Toward the Bottom.
G

FIG. 2.

was completed, it was assumed that the down-stream rock was too soft to continuously resist the erosion of the falling water. Therefore, a large space was excavated and filled with heavy stone, each containing a yard or more, and to a depth of 10 or more feet. The interstices between these stones were filled with grout containing one of Portland cement to three of sand.

On October 3d, in company with Mr. Geo. S. Cheyney, member of the Engineers' Club, who took the photographs (Figs. 1 to 6) herewith shown, the author made a visit to the Austin dam and

Fig. 3.

spent the afternoon in making as close an inspection of the conditions as possible. No detailed description will be given, as the Engineering News, Engineering Record, and other papers, in their issues of the week commencing October 2d, published very full accounts with abundant illustrations and photographs.

Briefly, the dam was approximately 544 feet long, had a width of about 30 feet on the base, and a maximum height of 51 feet. The top width is 2½ feet. The up-stream face was vertical and the down-stream face pitched at an angle of about 36 degrees with the vertical. This slope commenced about 12 feet from the top, where

the thickness was about 6 feet. Below the intersection of this slope, with the surface of the ground, the face of the dam is made perpendicular, evidently depending on the earth backing as a portion of the resistance.

This dam was completed on December 1, 1909. It was said to have

FIG. 4.

contained 15,780 cubic yards of concrete, 7,925 cubic yards of excavation, and 6,360 cubic yards of embankment. The cost is given as $71,821, this account appearing in the Engineering News of March 17, 1910.

It will be seen by those familiar with dam construction that this cost was very low, and that the ratio of concrete masonry to excava-


C
E
B
A
Looking Westward along Dam—Up stream Side

FIG. 5.


J
H
Looking Up Stream to the Northward and Showing Large Section Which Overturned and Fell Backwards Towards The Dam.

FIG. 6.

tion was extremely high. In other words, the amount of concrete was double that of excavation. Compare this with a few of the large dams of which the writer has recently had charge.

Name of Dam	Capacity in Gallons	Masonry, cu. yds.	Excavation cu. yds.
Tub Mill Creek dam, in the Chestnut Ridge, above Bolivar, Pa.	207,000,000	40,986	26,654
North Branch of Conemaugh dam, above Wilmore, Pa.	1,025,000,000	35,972	39,603
Indian Creek dam, nine miles southeast of Connellsville, Pa.	240,000,000	7,840	9,273
Lloydell dam, on South Fork Branch of the Conemaugh, ten miles above South Fork, Pa.	204,000,000	30,148	45,031

All these dams extended down into the rock a great depth. The Tub Mill dam went down to a maximum of 50 odd feet. The North Branch of the Conemaugh, about 40 feet. Indian Creek dam, to a maximum of 20 feet. Lloydell dam to a maximum of 80 feet. As these dams were solidly bedded against the down-stream rock vertical face there was no possibility of their sliding, which was, undoubtedly, the cause of the failure of the Austin dam.

The Austin dam was built of concrete, stated to be mixed in proportions of one, three, and six, and an examination would indicate that it was well built in about the proportions stated.

The sketch, Fig. 7, will show in plan and elevation about how the failure occurred.

According to the article in the Engineering News, the dam contained steel reinforcement uniformly located, but an examination of the fractures will indicate that this was not as shown. In fact, the reinforcement cannot be considered as of any value whatever, and it was unnecessary, except to prevent temperature cracks, or to anchor it to the bottom, but, as for either of these purposes, many times the amount used would be required, it is seen that this reinforcement is of no consequence whatever.

According to the same article, this dam practically failed in January, 1910, and how those responsible for the dam could have assumed that it was safe after that failure is almost inexplicable. The

case is parallel to that of a beam or girder uniformly loaded to such an extent as to cause it to crack in several places. The load being immediately relieved, the beam stands in its weakened condition, and, afterwards, when loaded up to even a greater extent than originally caused the break, final failure must inevitably take place.

It is said that at the time the dam was originally cracked, a hole was dynamited through it which caused the water level to go down, and naturally relieved the pressure. It is also stated that the reservoir had not been filled up again until just before the final failure. The information, which the author obtained second-hand, is that

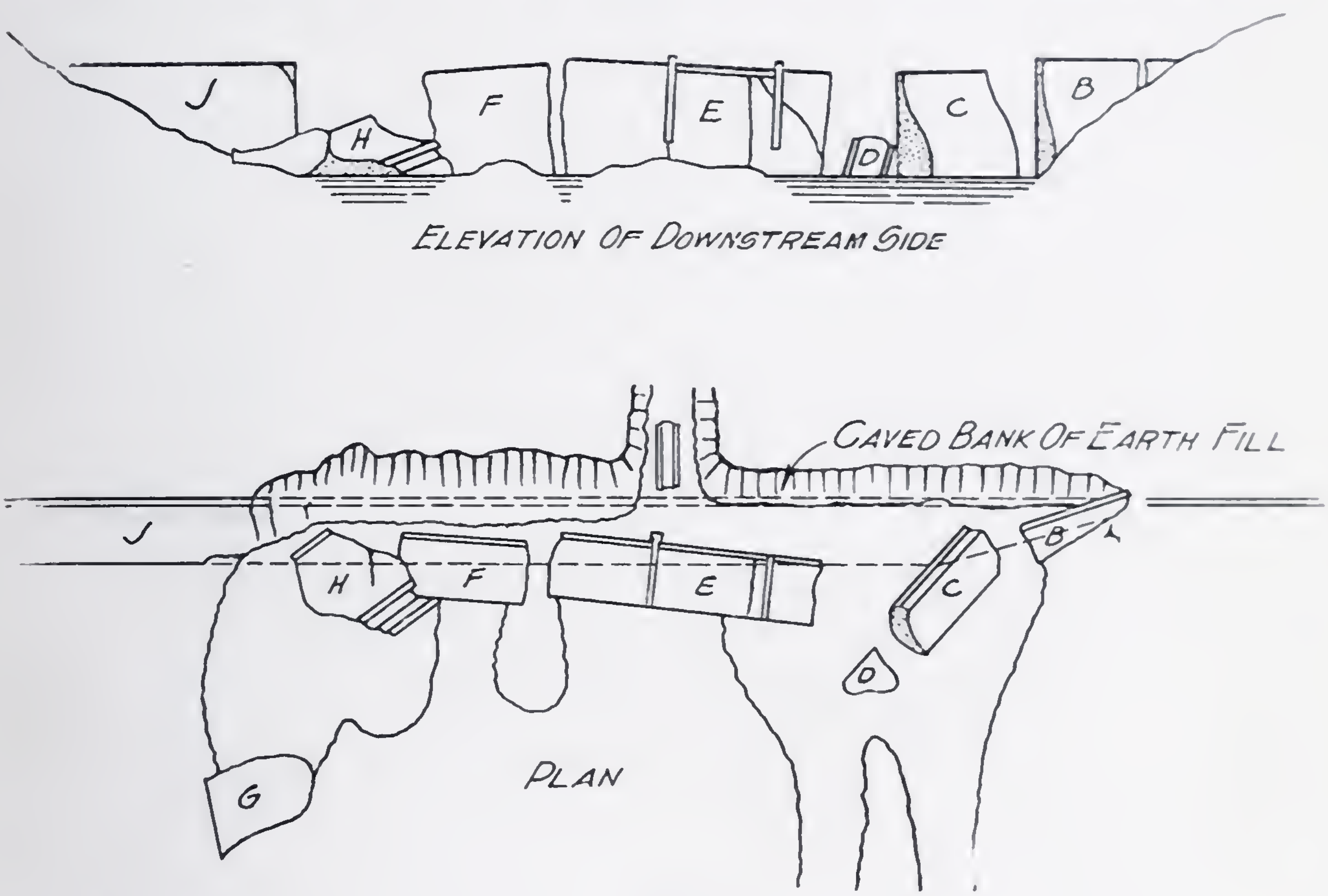

Fig. 7.

several women who lived near the dam, and who frequently walked out on it, noticed a general movement down-stream. One of them ran to a telephone and notified the operator at Austin. It required three or four minutes before the final bursting and release of the water. It is also stated that the wave required about seven minutes to reach the manufacturing plant of the Bayless Pulp and Paper Mill, which was three-quarters of a mile down-stream, and four or five minutes longer to reach the town of Austin, which was a half-mile below the paper mill.

It would seem, from the conditions and the position of the fractured

sections, that the dam must have failed by sliding, because all the large sections stand on their original bases, but at a considerable distance down-stream.

With the exception of two, all the lines of fracture were in existence more than a year ago, and observation showed that the fractures were partly along planes between concrete built at different times. In fact, in nearly all cases such planes could be seen, showing that they represented the lines of least resistance. In some cases these planes were horizontal and one of such planes at the west end of the dam was 30 odd feet long and passed through the entire section. Another plane that could be seen distinctly was several hundred feet long and probably represented the line between the finishing of one period of work and commencing of the next. This could be seen plainly on the down-stream side near the natural ground level. However, none of these fractures could be considered responsible for the weakness or failure of the dam. This was due to some deeper cause, and when the strain became too great, naturally, the breaks would occur along these planes of cleavage, but it must be understood, that if the dam was in other respects perfect, these cleavage planes would not have been a source of weakness. Such cracks may, however, be criticized, because temperature cracks are almost sure to occur at these places, and, therefore, water could leak through the dam, generally, however, in very small quantities. A gravity dam is built on the principle that, if it were sawed through transversely in sections of one or more feet in length, the sections would stand just as safely as if they formed one continuous solid mass. It has been said that this dam was built of boulder concrete, often called cyclopean concrete, but this is not generally true. Most of the dam was composed of concrete, pure and simple, with some boulders near the bottom. However, this is not important.

Now, if the dam failed by sliding, what was the cause? The weight of the concrete is found to be about 135 pounds per cubic foot, and, figuring the weight of the dam and its coefficient of friction against the rock underneath, it is found that there would not be anywhere near sufficient water pressure to slide the dam on the surface of the rock; and, judging from its appearance, the engineer or men in charge of the construction of the dam must have taken pains to see that the bottom of the dam was in intimate contact with solid rock surface. It is, therefore, entirely unlikely that sufficient water could percolate between the bottom of the dam and the rock to exert a

material upward pressure. Therefore the author is of the firm opinion that the failure was not due to the weakness of the structure itself.

If the dam were built upon a solid plate, underneath which were rollers, rolling in a down-stream direction, the conditions which resulted would have been fulfilled exactly; that is, the entire dam would act as a beam uniformly loaded, and if this beam were not sufficiently strong it would fracture near the center and probably at other places, and if there were any cracks due to temperature, it would fail at these cracks, and when final failure took place one might find fresh planes of fracture near each end, providing these were carried sufficiently into the hillsides to prevent going down in a body. This is exactly what took place, and an examination of the rock will indicate that there existed a condition quite analogous to the roller illustration. This rock belongs in the formation, known as "Catskill Sandstone," and at this point the sandstone exists in thin layers, averaging from a few inches in thickness to several feet, but at the bottom of the dam there was probably no very thick stratum. Some of these layers were parted by shaly clay, pervious to water. The upper surface of the rock looked good enough as a bearing surface for the dam, and therefore the builders did not extend the dam down into the rock any material distance. Probably, solid bed-rock was all they were seeking. The consequence was, when the dam was subjected to the full pressure of water, the upper layers of rock upon which the dam was founded slid on the layers below along one or more of these clay partings, and as there was nothing to resist this except a few feet of earth below the dam, the resistance was not sufficient to withstand the 250,000 tons of force, and, therefore, the entire dam with one or more layers of stratification moved down-stream, and pushed the earth ahead of it, and crumpled up the stratification in a manner very similar to what is seen at the foot of steep hills in the coal formation due to extensive landslides. (See sketch, Fig. 8.)

The upward pressure of water exerted between these layers of rock, no doubt, aided to facilitate this movement. This theory fully accounts for all the facts, as will no other theory that has been proposed up to date.

As to the question of where the blame lies for this failure the resident engineer, in charge of the work at the time the concrete was started, would probably be the best judge. The cause of the failure of the Austin, Texas, dam was stated by the engineers who made

the investigation, to be due to erosion by constantly falling water against the comparatively soft rock under the down-stream toe, this erosion having gone so far back under the dam as to make the structure unstable. Others have stated that the rock slid on itself causing the dam to fail by sliding in the manner above stated. With this possible exception the cause of the failure of the Austin, Pennsylvania, dam seems to be unique, and, therefore, the judgment of the engineer who was in charge of the work at the time the excavation was completed might not be severely censured in view of the accumulated knowledge and state of the art up to that date. It must be remembered that he was working for a corporation who desired to

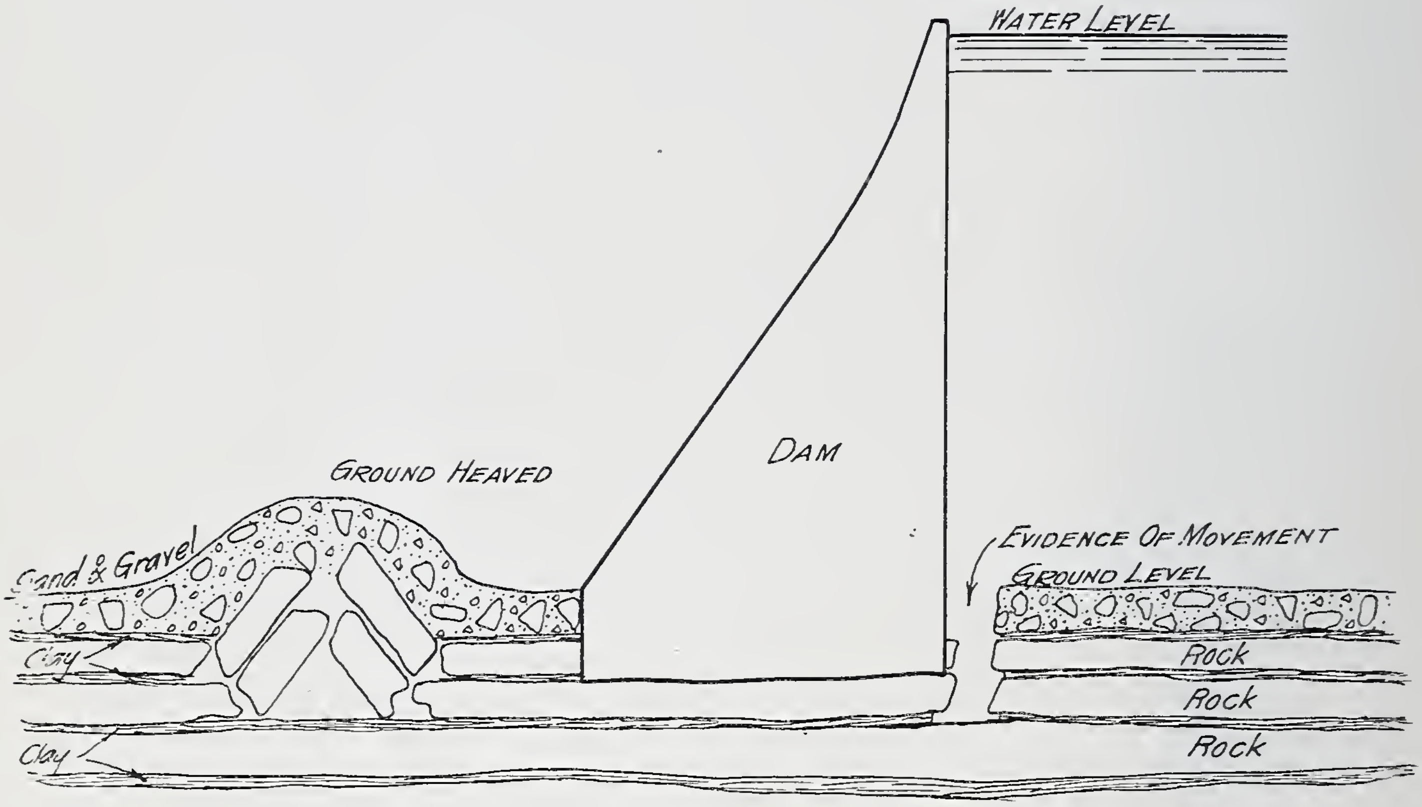

Fig. 8.

build this dam at the lowest possible cost consistent with safety. The engineer saw the surface of the rock as it was exposed to view, and found that it was clean and hard, and certainly possessed sufficient bearing power to withstand the downward pressure. He was also positive that the coefficient of friction between the concrete and this rock would be sufficient to prevent sliding. He had probably sunk test holes enough to indicate that the character of the rock for a considerable distance below the surface was not any more solid or suitable for a foundation. Therefore, he saw no reason to go deeper, or to believe that the dam would overturn or slide on this rock surface. His reasoning up to that point was absolutely sound, and

this would naturally have been sufficient for a great many engineers of standing who desired to save for their employer every possible dollar. However, it is certain that the vital weakness must have been overlooked. The coefficient of friction between hard concrete and sandstone rock, even under the smoothest conditions, is at least 0.70; that is, horizontal, it takes nearly three-fourths as much force to slide a body as the body has weight, but where the concrete is laid on the roughened surface of the rock with indentations, the coefficient of friction would be a great deal more than this, and probably over unity.

This dam weighed about 9400 pounds per lineal inch, and the pressure of water against the dam was about 6300 pounds per lineal inch, so the dam had a factor of safety against sliding of as much as 1½, but now, the coefficient of friction between two rock layers separated by a layer of pure clay is only $\frac{1}{3}$, and when the clay is moist, may be even less, so dividing 9300 by 3, there is found a trifle over 3000 pounds per lineal inch, while the pressure of water was 6000 pounds per lineal inch. It is, however, not likely that the clay was in a pure state, or of a sufficient thickness in any one stratum to reduce the coefficient of friction to .3, but it will be seen from the above calculation that it would not have to be reduced to less than 0.6 to cause sliding. The resistance of the bank of earth below the dam, which bank was probably not more than 6 or 8 feet high, would be trifling and it would not exert more than 300 or 400 pounds per lineal inch against the dam, but there is a matter of probably 2000 or 3000 pounds to resist. Therefore, due to these conditions which are plainly seen in the nearby quarries, sliding in the manner indicated is almost certain to have occurred.

If this, then, was the cause of the accident the remedy would have been, as soon as the structure was seen to be weak, to construct below the dam, a wide trench to a depth of 10 or more feet below the rock surface, and this should have been carried up to 4 or 5 feet above the bottom of the dam so as to form a bulkhead or barrier to prevent sliding. The thickness of this wall should have been sufficient to prevent its breaking off due to shear and beam action necessary to resist the sliding of the dam. A thickness of 15 or 20 feet, and a depth of 10 feet below the surface of the rock, would have been ample for this purpose. Of course, this could be built instead of rectangularly in such a shape as to form a brace or strut against the toe of the dam.

In order to stop the excessive leakage, as well as to prevent pres-

sure acting upward against the dam, it would probably have been worth while to sink a deep cut-off trench on the up-stream side of the concrete masonry, and to a depth of 15 or more feet. This trench should have been filled solidly with concrete which should have extended slightly under the dam.

All this could have been obviated, originally, by carrying the dam down 5 or 10 feet deeper.

There is one feature of the construction of the Austin dam that is particularly noticeable and which was mentioned earlier in this paper. The down-stream slope, in all cases, ends at a very short distance below the natural surface of the ground, which would be perfectly justifiable, if the natural ground were solid rock high in resisting power; but, it would certainly not be justifiable when the material is sand, clay and gravel as in this case. An examination of the diagram of the resolution of forces (Fig. 9) shows that the resultant comes within the middle third at all points above the intersection of the slope with the vertical down-stream face; but, below this point the resultant falls considerably beyond the middle third. However, this analysis is not of great importance in view of the fact that the dam did not fail by overturning but by sliding.

As a general proposition, engineers designing masonry dams are not required to give much consideration to the danger of sliding. In the great majority of cases it is necessary, for other reasons, to go to a depth considerably below the rock surface, and this, by proper construction, can be made a bulkhead to resist the sliding of the dam.

From the calculations given above it will be seen that the effect of possible upward pressure was not considered. Neither is it average practice to allow for this upward pressure which, theoretically, might reach a maximum of half the hydrostatic pressure acting upward against the entire base of the dam. The most conservative practice assumes two-thirds of this hydrostatic pressure at the up-stream toe and zero at the down-stream toe. The average pressure would then be one-third of the hydrostatic pressure, and if the forces are as assumed, the resultant of this upward pressure would act at a point distant from the up-stream toe equal to one-third of the base. But as there are a large number of important dams standing safely today, whose section does not take this into account, and which would fail if the upward pressure acted according to this theory, it is evident that it is not by any means a certainty; but, hereafter, no doubt, it will be allowed for in all important structures. The danger of

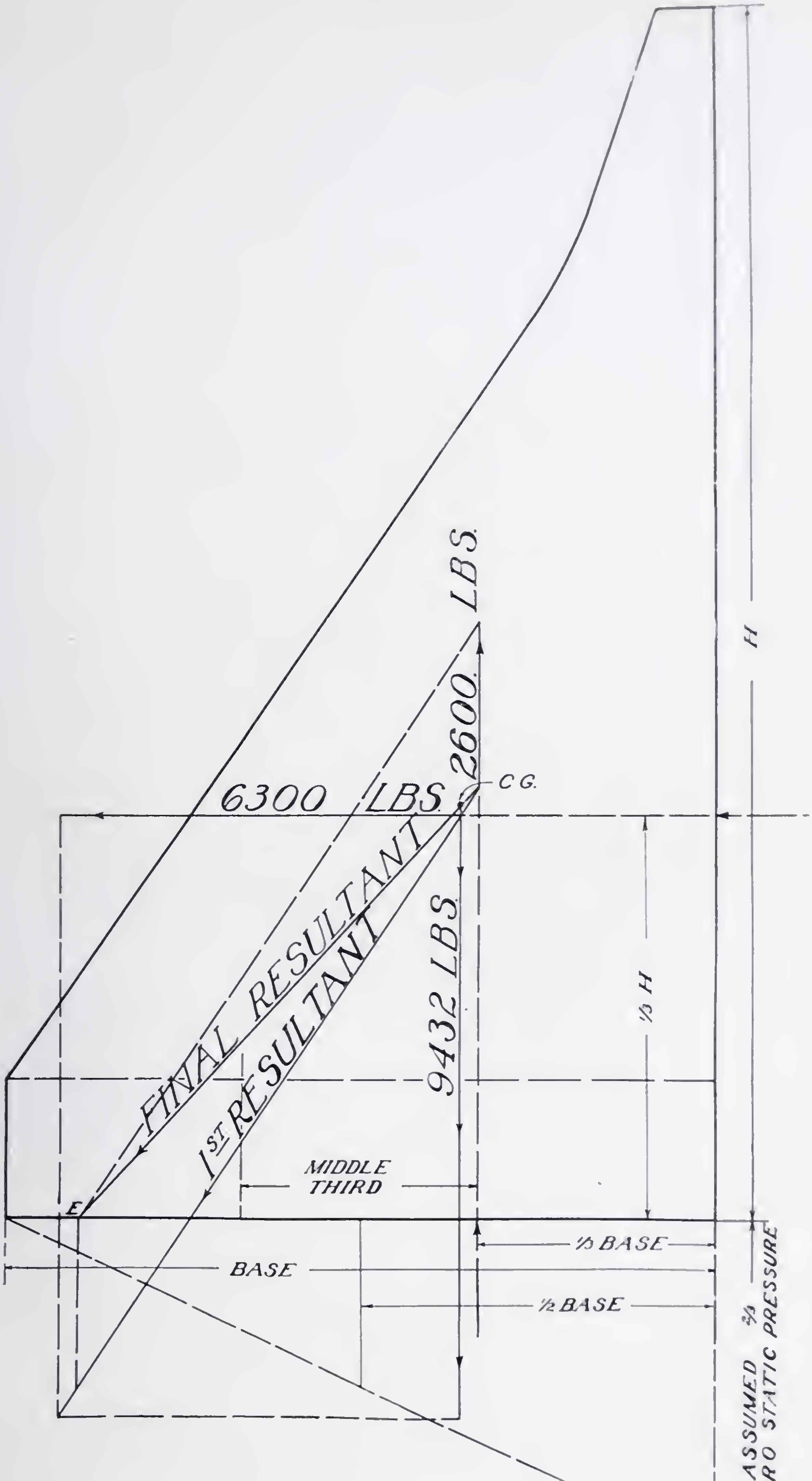
6300 LBS.
2600. LBS.
C.G.
FINAL RESULTANT
1ST RESULTANT
9432 LBS.
H
1/3 H
E
MIDDLE THIRD
1/3 BASE
BASE
1/2 BASE
ASSUMED 2/3 HYDRO STATIC PRESSURE

Fig. 9.

upward pressure, however, can be obviated by a not very difficult expedient, and without increasing the section of the dam, in the following manner: It is always advisable to found the up-stream tce on a cut-off wall, say 4 or 8 feet thick, and extending down a considerable depth. When this is constructed it is incorporated with the rest of the masonry and forms a very effective barrier against leakage. If this wall is depended upon for water-tightness, the intersection between the remaining part of the bottom of the dam and the rock can be made porous. For instance, the first 6 inches or more of the bottom can be built in the form of almost a dry wall, and, of course, this would save considerable expense over building the entire section large enough to withstand the upward pressure.

DISCUSSION.

Manton E. Hibbs.—As we have discussed the dam from its technical and mathematical points there is one question we ought to look at aside from that of engineering, and that is, the safety of the people in the vicinity of the dam.

I believe there should be somebody in the State of Pennsylvania to place a check, not really upon the safety of the dams themselves, but the safety of dams with regard to the people they affect. For example, take the case of a river whose natural course is changed, dammed up, and made dangerous by a corporation. Shall the corporation be allowed to do as it pleases, or shall it be compelled to protect the people? When it comes to a question of money-making you will find the safety of the people gets small consideration, and I believe there should be some check upon the owner and the engineer. This will not retard the work of the engineer or owner in any way and the most efficient will win out in the end.

I am not criticizing so much the engineer who designed the dam with regard to the loss of life, but, merely, to look at the matter of safe construction and its responsibilities. The responsibility rests, first, with the engineer who designed the dam, then with the people who employed him, and the contractor who superintended the construction. Finally, the State should assume responsibility. It is only through the harmonious relations of these different elements that safety in a structure can be insured.

Edwin F. Smith.—I cannot add much to what Mr. Ledoux has told us about the construction of dams. There is one thing, however, that impresses me and it comes to my mind from time to time as horrible accidents like this happen and it is this: that engineers should be more careful about foundations when building such structures. It is not sufficient to start the foundation of either a masonry dam or a timber dam when we touch rock; it is not sufficient to put down drill holes to ascertain what is the character of that rock; it is better to sink shafts and go down to the bottom until we find we have solid rock and a good foundation. A dam, such as that at Austin, should not be built upon rock that is in alternate layers with clay, or even hard pan, between the layers. We should not build foundations for a concrete dam on anything but bed-rock, rock that is

impervious to water. That is what should have been done at Austin. To have built on rock that was separated by layers of clay was a mistake, and was inviting trouble, and it is entirely without explanation or defense. The dam should have gone down to bed-rock and then there need have been no provision made for the upward pressure of water. If the entire structure from foundation to top is impervious to water there will be no upward pressure.

I think every dam of that kind should have a cut-off wall, but, I prefer that it should be placed under the middle of the dam and made large enough to act both as a key and as a barrier to any water finding its way under the foundation of the dam. That is easily done. It adds something to the cost of the dam, but it does not require the expenditure of a large sum of money, and there should be enough spent on such dams to make them entirely safe.

I have read a statement in the Engineering Record that there is now suspicion attached to the work of engineers in regard to such structures because of the calamities that have happened. There should not be any such criticism of the engineering profession as a whole, based upon isolated cases or a few instances of failure. There is good engineering and there is bad engineering, but that should not condemn the profession of engineering.

Mr. Ledoux.—I do not agree with the last speaker that engineers should not be criticized. I think we should look for the truth, no matter where it occurs, and no matter how serious may be the consequences to the engineer. Mr. Hatton is an engineer of ability. If he is responsible for this design he went pretty close to the danger point. Still the course of failure was not due to the design but to the lack of depth in the rock. But I think the dam would have stood all right if it had had a rock barrier to resist it which would have been effected by excavating to 10 feet into the rock. You are sure to have some upward pressure, and I agree with the last speaker about making the up-stream side impervious to water.

Carl P. Birkinbine.—The failure of the Austin dam, now under discussion, brings up a subject that has been recently treated by the technical magazines, and to which the engineering profession should give consideration, viz., What legislation, if any, should be recommended to best assure that dams in use, or to be built, are stable?

It would be comparatively easy to provide for future constructions by demanding approval of plans, specifications, knowledge of foundation and abutment, method of connecting the structure to them, and such critical inspection of the work in progress as will demonstrate if it is prosecuted in conformity with the plans. A provision of importance would require that plans be made by, and construction be under the supervision of a competent engineer.

But the determination of stability of dams in service is far more difficult. In many cases plans and specifications are unavailable, nor can accurate knowledge be had of method or details of construction. Information relative to character of underlying foundation can only be assumed from the geology of contiguous territory. The method and detail of construction, and the care used are hidden, and judgment must be passed on the apparent condition, and calculation of stability made upon an assumption of good construction, while the risk of injury must be gauged by extent of spillway, height and design of abutments, and facilities for withdrawing or wasting excess water in case of necessity.

Legislation should cover not only the design and construction of dams, but provision for knowledge of the care in operation, for neglect, carelessness, or unappreciation of conditions may seriously jeopardize an otherwise satisfactory structure. Such an example was given us 22 years ago by the Johnstown disaster, in which the failure of a dam was a contributing cause, yet this structure had stood for a half century and showed no signs of weakening until abused. The removal of drain pipes and placing a fish screen across the spillway greatly reduced the facilities for wasting excess, and the improper filling in of the pipe trenches, left a depression. With extreme rain-fall conditions and resultant clogging of the screen by débris the outlet was insufficient and the further weakening of the embankment as the water rose, by turning a furrow to make additional height, permitted the water to spill over and cut the entire embankment when overflow had once begun.

The growth of population and the desire for uncontaminated sources of water supply require more and larger dams and reservoirs, sometimes of considerable depth. The development of water power is continually growing, in which the maximum practicable fall is desired, while seasonal variations in precipitation create a demand for storage basins to augment the stream flow at periods of low discharge. The quantity of water required to increase the available power for a number of days, perhaps for months, demands storage facilities often of enormous capacity; quantities that make appear insignificant the contents of the Austin dam, which did not exceed one day's supply for the city of Philadelphia.

Mention was made this evening of a printed statement that the public was losing confidence in engineering, a statement which seems best combatted by facts, viz., the immediate acceptance by the people of engineering work, such as the rental of office space in extremely high buildings, or the utilization of river tunnels, etc. And although the Austin and Johnstown dams are not the only failures, the others have fortunately done little or no damage; yet their total is a very small proportion of the number of existing structures; a fact which can assure the public.

In the matter of construction I believe that there should be some advocation by the profession for authority to the engineer. In many cases the authority is divided between the engineer and his clients, but it is not difficult to guess where the responsibility of any fault is placed. Or, in another instance, it is manifestly unfair to both parties, as well as to the public and the profession, that a well planned design should be taken from an engineer and built according to the idea of some one else who may or may not be fitted. For I believe that an engineer given full authority would willingly accept the responsibility.

Public demand for legislation is justified in view of the fact that many existing dams had been built with no approval beyond a charter right, and under no compulsion of stability of design, character and quality of material, and construction or care in operation. The technical publications as well as some engineers have been advocates of governmental control. Any legislation should be both protective and fair, and of such character as to appeal to the public, not only now but at other times. And with a trend of sentiment in this direction, the engineering profession should well consider this matter, and suggest such action as it deems advisable and equitable.

John C. Trautwine, Jr.—There would seem to be no question as to the

soundness of Mr. Ledoux's conclusion that the primary cause of the failure of the Austin dam was the sliding of the upper rock layer, in which the dam rested, over the lower layers, the sliding being facilitated by an intervening stratum of shale or disintegrated rock, through which the water, from the pool above, percolated, under pressure, diminishing the downward pressure of the dam and the upper rock layer, combined, and lubricating the relatively porous stratum through which it flowed.

The published accounts of the failure, however, make it apparent that there was another and secondary cause of failure.

These accounts inform us that the maximum down-stream movement of the dam, at its base, was 18 inches, while that of the top, at the same point, was 31 inches, or 13 inches greater, showing that this portion of the dam, in moving forward with its sliding foundation, also tipped forward. This is confirmed by one of the photographs which shows extensive spalling of the down-stream toe.

If the toe pressure suffices, as in the Austin case, to spall off the material there, the base is thereby, of course, narrowed, and the resultant brought still nearer to the toe, and so on. Besides, the weight of the dam resists overturning by a leverage equal to the distance from the toe to a vertical passing through the gravity center of the cross-section; and the spalling of the toe probably diminishes this leverage, and thus the resisting moment, while the destructive leverage and moment of the water pressure, behind the dam, presumably remain undiminished.

I cannot help wondering why Mr. Smith prefers to place the cut-off wall under the center of the base of the dam. Placed at the up-stream heel, as provided in the design of the Austin dam, it must, if effective, keep the water from under the dam; whereas, if the cut-off wall be placed under the middle of the dam, the up-stream portion of the dam may have water beneath it pressing upward just where such pressure is least desirable.

On other occasions, I have had so much to say here, on matters connected rather with sociology than with engineering, that I should not dare to mention them now if they had not been brought up by Mr. Birkinbine.

We hear much of the beauties of individual freedom, of the importance of letting every man do just as he pleases, and of the danger of interfering with him. We are reminded that the corporate-managed railroads of England and the United States are run with greater energy than are the State-controlled roads of the continent, etc., until we are fain to go back to the individualistic days of the private pump and well; but, we must not forget that, as our corporations grow in power, the individual becomes more and more helpless to protect himself against them, and it becomes more and more necessary for the State to interfere for his protection. The Austin dam failure furnishes a case where more State control would have done no harm.

Fifty or a hundred years ago we were all approximately of one size and no corporation was big enough to be a serious menace to the individual. That "things are different now" is shown by the necessity for building inspection and for boiler and food inspection. Paternalism may be very unfortunate, especially from the view-point of the parties regulated, but it is the inevitable order of the day.

J. E. Gibson.—Regarding the proposed enactment of legislation giving the State the right to pass upon the design of dams and other structures, I do not

believe this will accomplish very much unless we can get a higher class of men to act as our legislators, governors, etc., and a greater number of competent and experienced men willing to act upon our public commissions. We now have a number of good laws looking to the protection of the public morals, sworn officers of the Court, and an efficient police force to enforce them; still all of us realize what a farce the enforcement of these laws becomes at times.

It is generally conceded, I believe, that the Austin, Pennsylvania, dam failed on account of defective foundations and under the proposed legislation it would be the duty of the one appointed to pass not only upon the design, but also upon the foundations and methods of construction of any proposed dam. Let us take a concrete case:

John Doe, desiring to construct a dam, will submit a set of drawings to the State for its approval; should the design not be a proper one the State will insist upon changes being made before it will grant its approval. The next step is the construction, and here again, the State steps in and passes upon foundations, etc., insisting in all cases of doubt upon its view being carried out. The net result is that the State, through its appointed officers, becomes virtually John Doe's engineer from the time the plans are submitted to the final and successful completion of the work. I believe that we, as members of the Engineers' Club, do not want to see this.

Referring to the editorial in this week's Engineering Record I agree with Mr. Smith that good engineering is not open to criticism and should not be criticized. Nevertheless, a failure such as that at Austin reflects on all engineering and the good suffer with the bad. The evidence of this is seen in the agitation by the inhabitants of the valley of the Croton River for an investigation of the new Croton dam. Another case is that of the public water supply for Columbus, Ohio. Columbus, I understand, several years ago, constructed a dam for impounding a new water supply, but on account of financial and other reasons the dam was never completed to its designed height. Now that additional water is required, it is proposed to complete the dam, but the citizens of Columbus have overruled their engineers, who are men of high professional rank, and have decided that, in view of the Austin failure, they will not complete their dam.

The Engineering News in an editorial, issue of October 5th, states that "the lesson of Johnstown fell upon deaf ears." I do not think the statement is warranted. The Conemaugh dam failed by overtopping and erosion, whereas the Austin dam failed primarily from faulty foundations, which is an entirely different condition.

The week following the failure of the Austin dam there were two failures in Wisconsin. These dams were composed of masonry spillways flanked on each side with earthen embankments with core walls. The cause of the failures was the overtopping of the earthen embankments due to inadequacy of the spillways; in this connection, I think engineers, as a rule, make a great mistake. Let us for a moment consider the spillways:

The upper, or Dell's dam, had a masonry section about 285 feet long by 29 feet high which acted as a spillway section. The spillway proper was 260 feet long and was designed to carry a depth of water of 5½ feet; and, in addition, there were four 4 feet by 5 feet sluice gates through the dam. The remainder of the dam was of earthen embankment approximately 500 feet long, with a

maximum height of 25 feet above the rock foundation, the top being 6 feet above the spillway crest. The slopes of the embankment were two to one. The core wall was of concrete 3 feet thick and resting on bed-rock. The drainage area above the dam was 950 square miles.

The earthen embankment had been reinforced by a sand-bag dyke raising its elevation 2 feet so that at the time of overtopping there was approximately 8 feet of water going over the masonry spillway. Using the formula

$Q = 3.15 \times 260 \times (8)^{\frac{3}{2}}$, where

Q = cubic feet per second, we have the discharge as 18,520 cubic feet or 19½ cubic feet, per second, per square mile.

The Hatfield dam, 6.3 miles below the Dell's dam, was of cyclopean concrete, flanked on either side by abutments of concrete and earthen embankments, to a height of 11½ feet above the spillway crest. The spillway was 490 feet long and designed for a depth of water of 10 feet. The west embankment was low and about 4000 feet long. The east embankment was over 1100 feet long with a maximum height of 26 feet. Slopes two to one.

These embankments had center core walls, with a width of 2 feet on top and a batter of 12 on one on each side. The drainage area was approximately 1350 square miles. At the time of the failure the depth of the water passing over the spillway was 11.3 feet.

Using the same formula as used above the quantity of water passing this dam at the time of failure was 58,600 cubic feet, or 43½ cubic feet, per second.

In the Johnstown flood the discharge, per second, per square mile, reached 400 cubic feet or more and to provide a spillway of a capacity of only approximately 45 cubic feet per second, on a drainage area as small as 1350 square miles, is, in my opinion, very bad engineering, and I would say that anything under 150 cubic feet per second, per square mile, for a drainage area of this size, especially where earthen embankments are used for a portion of the dam, is very questionable practice.

Some will state that the lower, or Hatfield dam, would probably not have failed had the Dell's dam not failed, but, in engineering, one must always consider the maximum stress that a structure may be called upon to withstand.

The placing of masonry core walls in the center of earthen embankments is I think questionable, as they offer no stability or protection other than against burrowing animals, and, possibly, seepage. Necessarily, the up-stream portion of the embankment becomes thoroughly saturated, and should the lower portion of the embankment be poorly constructed or fail for any cause, such as overtopping and erosion, the only resisting power is that of the core wall. This being of light section fails as a retaining wall for the saturated up-stream half of the earthen embankment. This is actually what occurred in both the Dell's and Hatfield dams. The crevasse in the Hatfield dam was about 500 feet long and the core wall overturned, breaking into several sections, from 30 to 50 feet long.

I do not think it is the intention of engineers, as a body, to criticize Mr. Hatton for the failure of the Austin dam. We will admit that the dam was built apparently with the one object of economy and that the section was reduced to the minimum. However, it is probable that had not the dam failed in its foundations, it would have withstood the hydrostatic pressure.

The dam actually failed in 1910. Mr. Hatton, realizing that he was responsible

for the design and would be criticized, at once called in Mr. Wegemann who is considered an authority on designs of dams. Mr. Wegemann made a report to Mr. Hatton, recommending certain changes, which, in his opinion, would make the dam safe. I feel sure that Mr. Hatton incorporated Mr. Wegemann's report, with one of his own to the Bayless Pulp and Paper Company, and in this action he did what any of us would have done to have corrected a piece of defective work. Why the Bayless Pulp and Paper Company did not carry out these recommendations, or at least see to it that the dam was not filled again, is inexplicable.

I am not opposing State control, for I think some form of State control of this class of structures is inevitable, but I am opposed to it unless it is more wisely administered than heretofore; and, in this connection, I want to bring out the fact that the State does not give sufficient reward in the way of salaries to induce men of ability to enter its employ. Public officers do not receive sufficient salaries to induce men to make a study of political government, and men who have the executive ability to act as the governor of a State such as Pennsylvania, can earn salaries many times larger as executive heads of the great corporations; and in addition, they are not subjected to the criticism and gibes of the public.

Massachusetts and Colorado have State supervision and I would add that both of these States have had failures of dams within the past few years.

Wm. Copeland Furber.—I want to endorse the remarks of Mr. Hibbs regarding State control. I think it should be accepted without argument that anything of a public or semi-public nature affecting public interests in any way should be supervised by some public officer, and whether the officer is efficient or not has nothing to do with this principle. The responsibility for the efficiency of the officer rests entirely where it belongs, on the shoulders of the people.

I do not know what condition our cities would be in today if there was no municipal bureau of building construction and inspection, and if the owners were allowed to exercise their own ideas of economy in building construction, and in this connection I would say that it is my belief that the powers of the municipal bureau should be increased rather than diminished in such matters.

I do not think that the engineer or the architect should ever fear State control. On the contrary, I think he will find the State or Municipal department for supervision of construction will back him up when he should be backed up, and will prove a tower of strength in circumstances where greed, stupidity or lack of intelligence on the part of the owner would produce disastrous results.

PAPER NO. 1106.

THE PRESENT ACTIVITIES OF THE COAST AND GEODETIC SURVEY.

O. H. TITTMANN.
(VISITOR.)

Read November 4, 1911.

THERE are various reasons why the head of the Coast and Geodetic Survey should be particularly glad to speak to an association of his colleagues in the engineering profession in Philadelphia. Philadelphia stands in a certain maternal relationship to the Coast Survey for, when the question of organizing a survey was up, the government turned to members of the American Philosophical Society for counsel and guidance. In response to the circular of the Secretary of the Treasury, calling for plans for the conduct of a survey, thirteen plans were submitted. These were fortunately referred to the then Vice-president of the American Philosophical Society, as Chairman of the Committee, to decide on the adoption of the best plan. The Committee endorsed the scientific methods proposed by Mr. Hassler who became the first Superintendent of the Survey.

It was a good example to set, but one which the government has not always pursued, to have the fundamental principles on which a work of applied science should be done, submitted to scientific men for consideration. To engineers it may seem as though no other way could have been chosen, than the one that prescribed a trigonometric survey as the basis of an extended survey, but as a matter of fact other methods were proposed. These things occurred in 1807, from which date it is seen that this Bureau is old in years, but facts will show that it is young in spirit, and strives to march in the van of progress, to lead where it can, and to follow only where it must. When the plans for a survey were made the Coast of the United States extended from Maine to Florida. The Floridas, much of the Gulf Coast, the Pacific Coast and Alaska were geographical conceptions outside of what is now the United States. At the present time the work of the Survey has been extended to the Philippines, the Hawaiian Islands, and other islands under the jurisdiction of the United States.

In brief language the following extract, from an official publication, describes the duties of the Survey:

"The Coast and Geodetic Survey is charged with the survey of the coasts of the United States, and coasts under the jurisdiction thereof, and the publication of charts covering said coasts. This includes base measure, triangulation, topography, and hydrography along said coasts; the survey of rivers to the head of tide-water or ship navigation; deep-sea soundings, temperature, and current observations along said coasts and throughout the Gulf and Japan streams; magnetic observations and researches, and the publication of maps, showing the variations of terrestrial magnetism; gravity research; determination of heights; the determination of geographic positions by astronomic observations for latitude, longitude, and azimuth, and by triangulation, to furnish reference points for State surveys.

"The results obtained are published in annual reports, and in special publications; charts upon various scales, including sailing charts, general charts of the coast, and harbor charts; tide tables issued annually, in advance; Coast Pilots, with sailing directions covering the navigable waters; Notices to Mariners, issued monthly and containing current information necessary for safe navigation; catalogues of charts and publications, and such other special publications as may be required to carry out the organic law governing the Survey."

It is because of the vastness of the subject that this paper is intended to touch upon present progress, conditions, and problems only and much that would be of interest and importance must be omitted.

The principal business of the Survey is making charts of the coasts. If there were no changes in the depth of channels, if the artificial aids to navigation remained fixed and unchanged, if the aspect of the shores from the navigator's viewpoint remained the same, if the draft of vessels remained the same, if the variation of the compass remained the same, if, in short, things were not as they are on this changing globe or the world were commercially fossilized, a survey once made would last forever. The actual facts are different.

Time was when it was a matter of small concern what dangers to navigation might lurk at a depth of more than 20 feet, but with the increased size and draft of vessels and their enormous cost, a revision and reëxamination of much of the old hydrography by new methods has become necessary. The channel sweep and wire drag now supplement the lead. After these new appliances have swept the bottom the Survey may look with equanimity on the evolutions of ten-million dollar battleships in our waters.

With every new chart that is published the Office assumes the respon-

sibility of keeping it correct, showing the changes in the magnetic variation, in the depths, and in the landmarks. This necessity, affecting the great number of charts that are published, engrosses the energy of the small force at the disposal of the Survey to so great an extent that it has become necessary to simplify the charts in many particulars. Not only do the results of these extended activities flow into the Office, but through the coöperation of the Corps of Engineers of the Army, its surveys for improvements are at once furnished to the Office. A hearty coöperation now exists between most Bureaus of the National Government.

When the publication of charts was first commenced they were engraved on copper in minute detail and with all the skill and beauty which the engraver's art could command. This system was followed until the problem of keeping the charts correct became one of overshadowing importance, on account of the detail shown on them not absolutely necessary for the navigator.

The first survey of the coasts having been completed it appeared possible also to reduce the number of charts by a rearrangement. Careful consideration of the economics of the problem showed that by such a rearrangement of limits, and by simplification, it would be possible to meet the ever increasing demands made on the Survey. These changes involve at the outset much work, but by following a consistent policy they can be brought about gradually without too great a strain on the resources of the Survey.

The tidal and current data hold a prominent place on the charts. In regard to the former, the charts give ample information, and this is supplemented by the publication of tide tables covering the world and which for completeness are unequalled by any publication devoted to this purpose. The Survey has recently completed a tide predicting machine of great scope and power. The theory of tides has been illuminated and advanced by researches made in the Bureau so that in this particular the Survey holds its place in the front rank.

In regard to currents, it must be said that much remains to be done, but this work has been delayed and crowded aside by the more pressing needs of commerce in other directions.

Just as the tide tables supplement the charts so do the sailing directions, designated as Coast Pilots, and to the preparation of which the labors of a number of experts are devoted.

Magnetics.—It is a part of the regular duty of the Survey to show

on the charts the magnetic declination and its annual variation. Unfortunately, the laws governing this phenomenon are unknown.

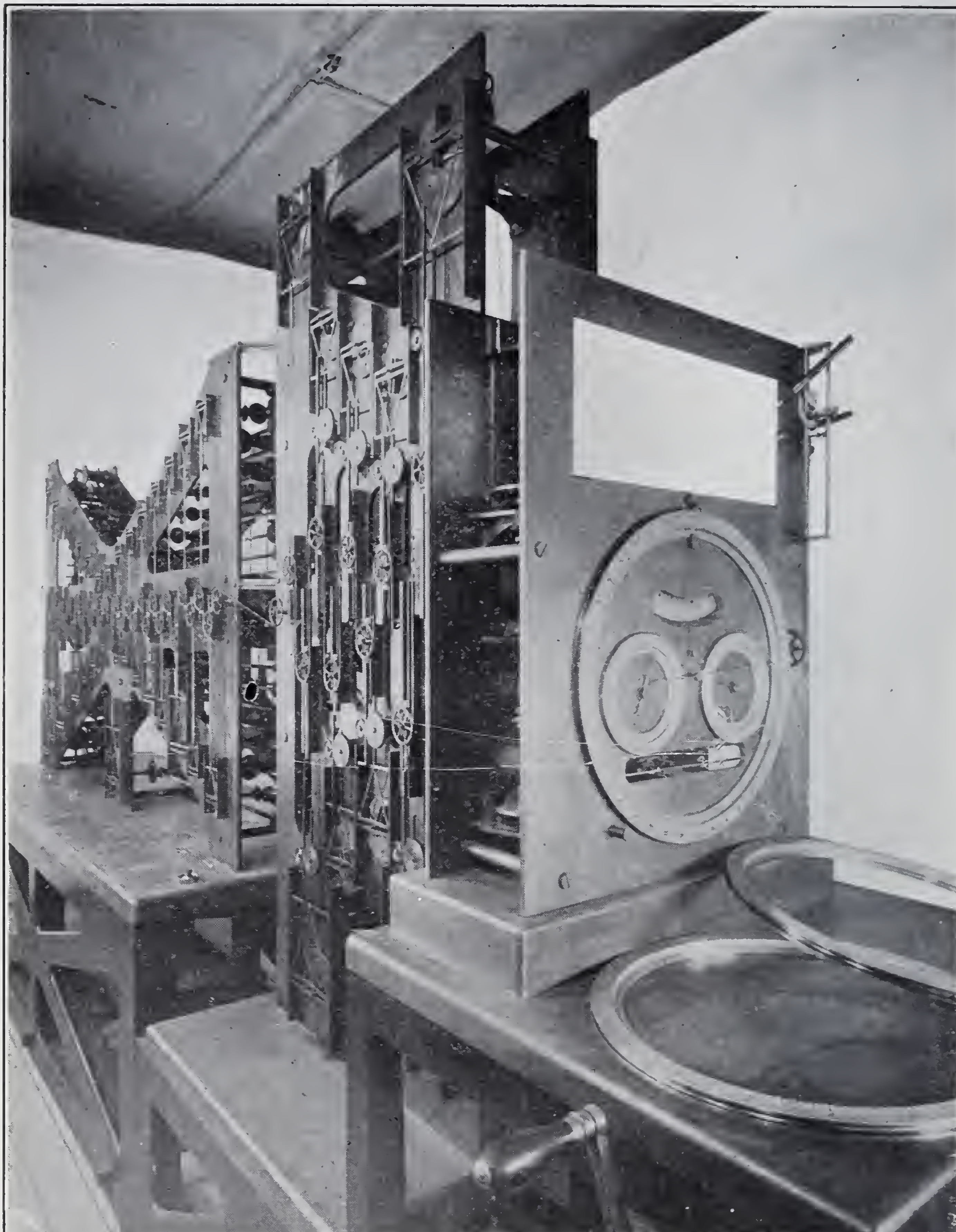

Fig. 1.—New Tide Predicting Machine of the U. S. Coast and Geodetic Survey.

Of late years Mother Earth has made a sudden acceleration of the rate of variation. Thus, along the coast of Maine, the change has

been from 3 to 6 minutes per annum and, on the far western coast, from 2 to 5, while the line of no variation persists fairly well in staying in one place. It is, therefore, part of the Survey's duty to record these eccentricities of the needle. As an important auxiliary to their detection, the Survey maintains a magnetic observatory in Vieques, an island lying to the east from Porto Rico; another in Maryland, a third in Arizona; one in Sitka, and one in the Hawaiian Islands. In all of these observations are made by continuous photographic registration. All the world is busy with similar observations, and whenever a scientifically equipped expedition, as for example the recent ones to the Antarctic, starts out, there is a general coöperation between the different governments of the world for the purpose of making simultaneous observations. It is to be hoped that sooner or later the mystery will be fathomed so that predictions of what is going to happen can be made.

The Triangulation and the Figure of the Earth.—In so extensive an undertaking as a trigonometric survey of the coasts and interior of our country it inevitably happened that surveys were made in detached localities, in Maine, in Florida, on the Gulf, and on the Pacific coast. Each area was referred to some local datum just as detached leveling would be. Gradually, these separate surveys were connected and it became necessary to adopt an origin of coördinates in reference to which all geographic positions should be expressed.

Every extended triangulation, whose determined positions and relative bearings are to be given, is developed on some adopted spheroid of reference. In the beginning Bessel's spheroid was used by the Survey. Later on the geographical positions were computed on Clarke's spheroid. An enormous amount of computation is involved in shifting from one to another and yet it is desirable to utilize all increase in knowledge of the size and figure of the earth.

In order to meet the difficulties presented by these conditions it was decided to separate the refined investigation of the figure and size of the earth from the practical requirements of using a spheroid, which should be sufficiently close for the practical requirements of the surveyor, the engineer, and the geographer. It is believed that the Clarke spheroid, of 1866, which was adopted by the Coast and Geodetic Survey, satisfies these latter requirements for the whole American Continent. The Survey next selected a particular point in the triangulation and a direction, and now, when triangulation is spoken of as being on United States Standard Datum, the meaning is that

the triangulation has been referred to Clarke's spheroid on which this particular point has a definite position.

Not only the Coast and Geodetic Survey triangulation, but that of the Lake Survey also, has been referred to this datum and wherever the topographic work of the Geological Survey has been connected with the triangulation of the Coast and Geodetic Survey it is equally referable to this datum. In this way has been achieved a homogeneous system of geographical coördinates for the vast domain of the United States, and it is not unlikely that Canada and Mexico will continue the same system.

It is not necessary to point out to engineers the practical value of a trigonometric survey. New uses for it continually arise. Witness the cadastral survey of Greater New York which is based on U. S. triangulation. The Oyster Surveys of the various States utilize the trigonometric points for the delimitation of the oyster-beds. The Coast Artillery is supplied with data which are used for fire control, and, in general, the network of triangulation forms a basis for coordinating all topographic and economic surveys, and thus the work accomplished is forever increasing in value and usefulness.

Among the unforeseen applications was the demonstration of the precise amount of the displacement of the earth's surface, by the San Francisco Earthquake along the fault line, and the extent of the movement at right angles to it.

Until about six years ago the method of deriving the figure and size of the earth from triangulation was to deduce it from measured arcs of parallels and meridians. That is, after the length of a meridional arc or parallel had been measured, the angle which its termini subtended was astronomically determined. But owing to the irregular distribution of masses on and within the earth's crust the actual direction of the Zenith differed from the geometrical Zenith of the spheroid of reference. This well-known error, called the deflection of the plumb line, was assumed to average out in a large number of arc measurements. At any rate no correction for it was applied.

A great many years ago, Archdeacon Pratt, while studying the pendulum observations made in India, reached the conclusion that wherever there were visible mountain masses such as the Himalayas there was a corresponding defect of mass in the earth beneath, but it was reserved for the Coast and Geodetic Survey to extend and apply this theory in the computation of the size of the earth from arc measurements by introducing into Geodesy what is now known as

the principle of Isostasy. This principle is that the matter composing the earth's crust to a certain depth has a tendency to adjust itself to a condition of hydrostatic equilibrium or has done so. Stated in another way, upwards from a certain depth below sea-level, each unit area has the same amount of mass above it whether we measure to the summit of mountains or merely to sea-level.

By trial computations, the most probable depth to which this compensation extends, was found to be about 122 kilometers, or 75 miles. Note how the work of the geodesist trenches on the domain of the geologist and geophysicist.

The hypothesis of isostatic compensation having been introduced, the effect of the visible topography for a distance of about 2500 miles was computed for each of the primary triangulation stations of the Survey, and the deflection of the zenith, previously referred to, was corrected at each station. Then the spheroid, whose surface most nearly agreed with the surface of the United States, was deduced and this gave the corrections to Clarke's spheroid. It is safe to say that the values for the compression and semi-diameters of the earth, resulting from these computations, are the most accurate known. It may be added that, when the results of this work were presented two years ago to the International Geodetic Association in London, the Americans were congratulated on having made a new epoch in Geodesy.

The Pendulum.—While one must rely on trigonometric observations to determine the size of the earth its figure can be determined by gravity observations, that is, by the pendulum alone. It is, therefore, a very important auxiliary in a Geodetic Survey. For the purpose of comparison the observations made with the pendulum must be reduced to sea-level. The manner of reducing them is one of the moot questions in Geodesy. Now, the recognition of the existence of isostatic compensation, which has been proved by purely astronomic methods, compels one to take it into account in the pendulum reductions. The method of reduction just introduced in the Survey not only does that, but, also, for each station, takes into account the effect of the attraction of visible masses for the whole earth. This is a great stride in advance; but the inevitable logic of this process has not been received abroad with open-minded enthusiasm. The correctness of the method has been proved for gravity work in the United States, and it is for others to show that it does not apply to the rest of the world.

The International Geodetic Association.—To make a new epoch in science is no mean achievement; but mention has already been made of the compliment paid to the Americans at the last meeting of the association in London. This association exists by virtue of a formal convention between the great powers of the world. It is an official organization whose object is to promote knowledge of the size and figure of the earth. Canada, the United States, Mexico, and Argentina belong to it. So do Japan and, practically, all the powers of Europe. It is one of the oldest of international scientific associations. The delegates to the meetings report progress, and compare methods and results, and endeavor to strengthen such undertakings as the Cape to Cairo Arc of the Meridian and the junction of the Great Trigonometric Survey of India with the Russian Survey. To carry out this last piece of work the association covets the coöperation of China and hopes that that ancient empire will ultimately join the other powers in the undertaking.

Among the tasks undertaken by the association is the determination of the variation of latitude. For this purpose, it maintains six small observatories in the northern hemisphere, two of which are in this country and are under the direction of the Superintendent of the Coast and Geodetic Survey.

Two years ago the astronomer in charge of the Observatory at Gaithersburg, Md., proposed the construction of a Zenith tube for photographically determining the variation of latitude and, at the author's request, the association gave about $2500 for the purpose. The instrument was constructed in this country, has been mounted, and the preliminary results indicate that a step in advance has been taken by securing a higher degree of accuracy, than was before attainable, with a considerable simplification of methods.

The association meets once in three years and the principal countries in Europe have vied with each other in extending invitations for meeting in their capitals. Although the Coast and Geodetic Survey has taken an honorable part in these meetings it has never had the privilege of extending the hospitality of this country to the association. Mention of this fact is made with the same embarrassment that the author feels in representing a great nation at such meetings, and having to maintain silence when the different nations of Europe are competing for the place of meeting.

The Geodetic Level.—Fig. 2 shows a picture of the leveling instrument, developed in the Coast Survey, with which nearly all engineers

are familiar. The instrument may be called a binocular level because there is a telescopic attachment by means of which the level is read by the observer without shifting his position. The level bubble itself is set into the telescope tube so as to be near the line of sight. Furthermore, the telescope tube is made of the alloy of nickel and steel called "invar" which has a coefficient of expansion of only about one-tenth that of steel.

The introduction of this level has added greatly to the accuracy of

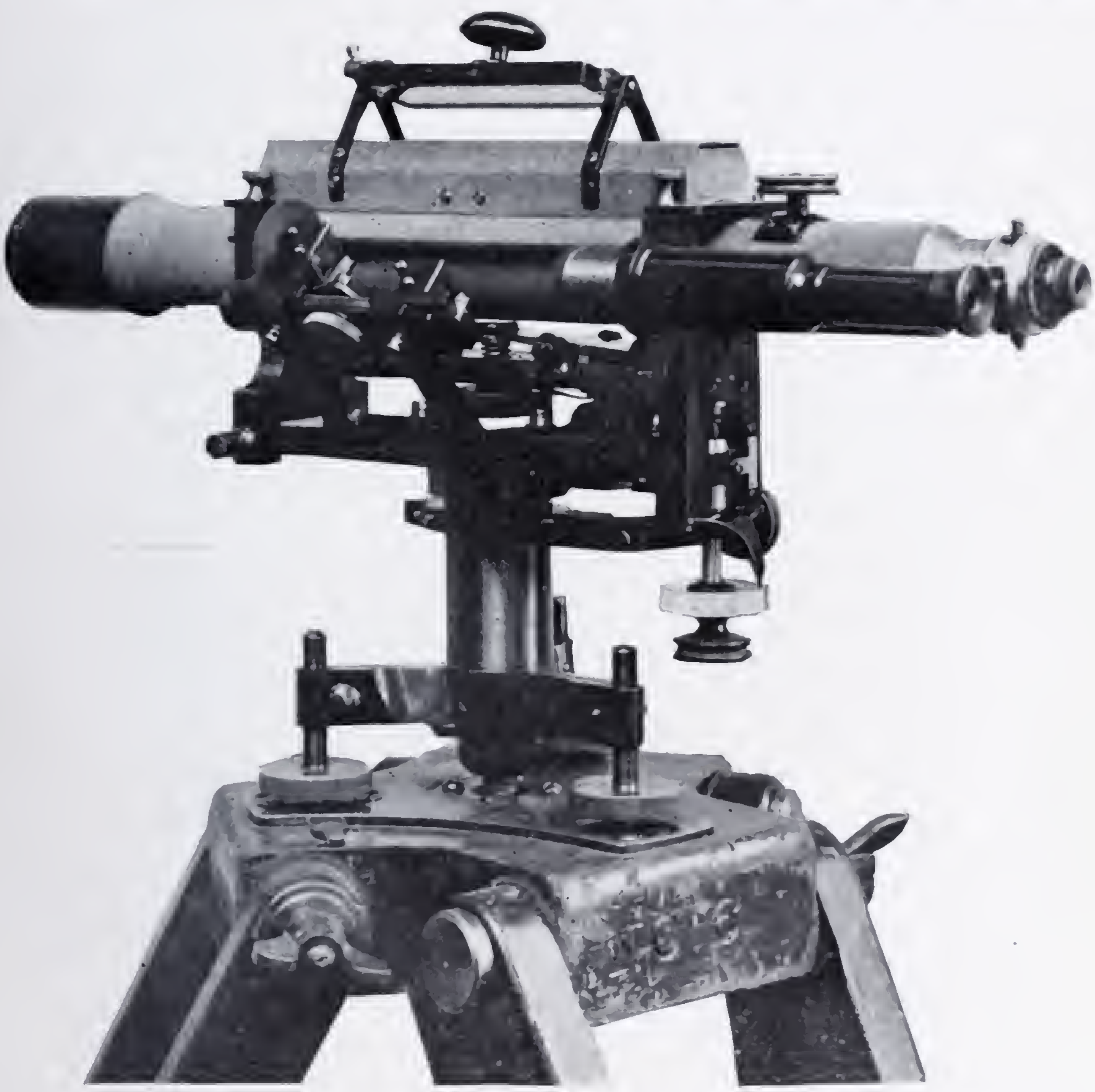

Fig. 2.—Geodetic Level used by U. S. Coast and Geodetic Survey.

the operations, the speed with which the best grade of work can be done has been much increased, and the cost correspondingly reduced.

In a slightly modified form it is in use in the Geological Survey. The Egyptian, Australian, and Canadian governments have also introduced it, and a recent report of the Director of the Great

Trigonometric Survey of India shows that a Commission was appointed to report on its merits, and that as a result of the report all their parties will soon be equipped with it.

The Coast Survey is not the only government agency engaged in leveling. The Survey confines itself to running standard lines which it connects with mean sea-level, at various points along the coasts, the datum planes being derived from long series of tidal observations. The coöperation between various agencies of the government is shown by the fact that all the principal lines of level, those by the Geological Survey, by the Deep Waterways Commission, the Mississippi and Missouri River Commissions, and by the Lake Survey, are utilized by the Coast and Geodetic Survey in a general adjustment which will serve for all time as the basis of heights in this country. The value of this work will continue to increase from generation to generation. The elevations of the bench marks in the precise level net east of the Mississippi River will be held as published, while the next adjustment will fix the final elevations of the bench marks in the net of precise leveling to the westward of that river.

One phase of leveling, which is of scientific interest, was connecting the mean tide level at San Diego with mean tide level at Seattle, where a difference of over 3 feet was found. Had the levels been run along the sea-shore from San Diego to Seattle, no difference would have developed assuming the work to have been accurately done. But as the lines were run up to and over high plateaus in the interior, and down again, it was found that the orthometric correction had to be applied, and this brought the operations into perfect accord. That is, the apparent difference of level was due to the route followed. This results from the consideration that two water-level surfaces, one above the other, will not be parallel as one travels north or south. In running east and west it makes no difference, but in running north and south this becomes a measurable quantity.

Our Northern Boundaries.—The Superintendent of the Coast and Geodetic Survey is Commissioner for the demarcation of the Alaskan boundary, and for that portion of the northern boundary of the United States extending from the Pacific Ocean to the Bay of Fundy, with the exception of the boundary running through the Great Lakes. The beginning of the settlement of the boundary, through Passamaquoddy Bay, goes back to the Treaty of Peace of 1782; the settlement of disputed questions was again provided for, in the Treaty of Ghent, in 1814, but certain portions of the line were not settled until

last year. Some portions of the line have never been laid down on any map but, generally speaking, the duty of the present commission is merely to fix up upon the ground, by surveys and monuments, the line where it has not been heretofore fixed with that particularity with which boundaries should be marked. The distance from the Pacific Ocean to Passamaquoddy Bay, along the boundary, is about

Fig 3.—Monument No. 76, Northwest Boundary.

3800 miles, 1200 miles of which are water boundary, running through the Great Lakes. When the boundary to the west of the Lake of the Woods was marked it was supposed that no one would ever feel any particular interest in this unsettled region, and that provisional marks or monuments at long intervals would suffice for all time. Needless to say, the settlement of this country brought

with it irritating questions as to the precise location of the boundary line. For the settlement of these questions a joint treaty covering the boundary from end to end was exchanged and ratified, in 1906, although prior to that time an international commission had been at work in a less formal way in restoring old monuments and tracing the boundary where international questions had made it necessary. The triangulation has been extended from the Pacific Ocean to the summit of the Rocky Mountains, and this part of the line has been monumented with aluminum bronze monuments, as shown in Fig. 3.

To the east of the Rocky Mountains this same thing has been done, at the present time, to within 100 miles of the Lake of the Woods, and the whole boundary has been carefully mapped, for a short distance, on each side of the line. Progress has also been made in surveying the thickly wooded region extending from Lake Superior to the Lake of the Woods, and further to the east the monumenting and surveying is in progress along the northern boundary of Maine.

All this work is done by international coöperation, under two commissioners, one representing Great Britain and the other the United States.

Probably more has been said of the demarcation of the Alaskan boundary than of this northern boundary. The Alaskan boundary work has been going on simultaneously ever since the tribunal, in London, in 1903, settled the vexed question of the location of the southeastern boundary of Alaska. The greater portion of this line runs from mountain peak to mountain peak over inaccessible fields of snow and ice. Starting on the 141st meridian, a little to the west of Mount St. Elias, the line follows these Alpine summits to the head of Portland Canal, and down that canal to the vicinity of the historic parallel "Fifty-four, forty, or fight," and thence to the Pacific. Wherever it was possible to place monuments it was done, especially at all river crossings in the passes; all of the mountain peaks were trigonometrically located and the region was mapped phototopographically. From photographs taken at determined trigonometric points maps were made by geometric construction. It is hardly necessary to say that the reports of the surveyors, who conducted this difficult and hazardous enterprise, are full of thrilling adventure, but only two lives have so far been sacrificed. Many of the men had the unpleasant experience of dropping into glacial chasms, from which they were rescued, but the two men who lost their lives fell into an abyss and their bodies were never recovered. The field work

Fig. 4.—Surveying in Alaska.

Fig. 5.—Mt Natazhat, 141st Meridian, Alaska.

of the southeastern Alaskan boundary has been nearly completed. The other part of the Alaskan boundary extends from the vicinity of Mount St. Elias, northward along the 141st meridian to the Arctic Ocean, a distance of about 600 miles. There never has been any international dispute as to that part of the boundary, which was defined by the treaty of 1826 between Great Britain and Russia. But for reasons not necessary to give here a new treaty was made in 1906 by which the Commissioners were instructed to determine,

Fig. 6.—Coming down over Snowfield, Alaska.

by means of the telegraph, a point on the 141st meridian and to trace a north and south line through it, extending from the Arctic Ocean to the southernmost point of this boundary. The physical difficulties of this work are very great owing to the difficulties of transportation and the shortness of the season. The difficulties of transportation are illustrated by the experience of two years ago, when the parties had to march 300 miles to get to the working ground. The plan of the work which is being carried out contemplates a north and south transit line along this meridian, cutting a line through the timber, planting aluminum bronze monuments in rock or cement bases at intervisible intervals, carrying on a triangulation which

Fig. 7.—Telephotograph of Boundary Peak, No. 7780, Southeast Alaska.

Fig. 8.—Wire Drag in Operation.

spans the boundary and the topographic mapping of a strip about two miles wide on each side of it. Aside from the immediate purpose of the delimitation, this work will serve as an admirable basis for co-

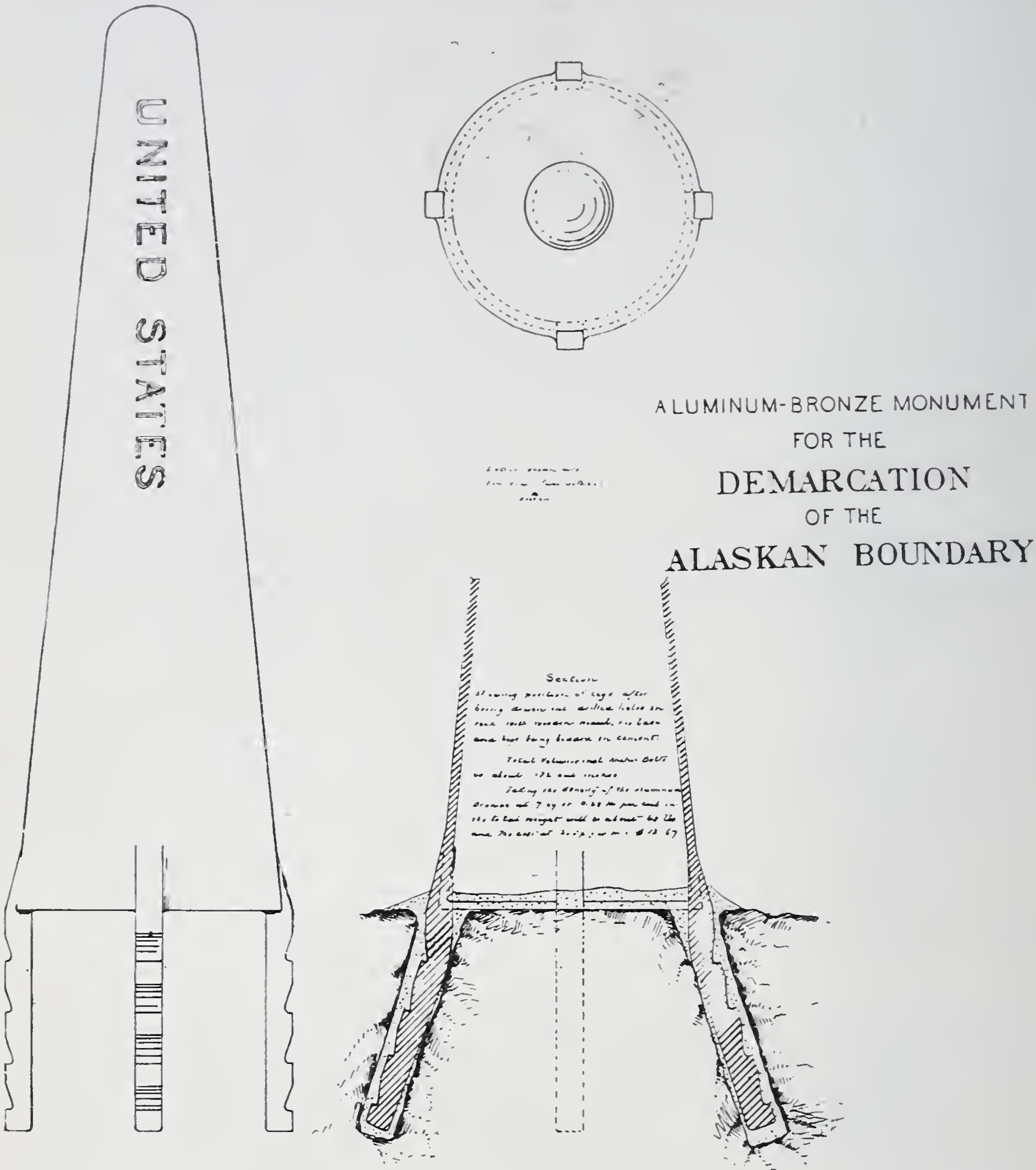

Fig. 9.

ordinating the land and economic surveys which will follow in another generation or two.

Fig. 5 shows the southern limit of the work which has been accomplished. It is only a provisional limit for it will be necessary to go about 90 miles farther south, through the mountainous ice field

which lies to the north of Mount St. Elias. Just what can be accomplished there remains to be seen for it is plainly useless to plant monuments on moving glaciers.

Toward the north, in the land of the Midnight Sun, the transit line has crossed a range of mountains whose crests are estimated to be about 7000 feet high, distant about 20 miles from the coast. The last station is about 7 miles from the Arctic Ocean. The topography, triangulation, and monumenting have not been finished quite so far, and the details of this work are not yet at hand, as the parties are only just returning after a very successful season. The season was marred only by an outbreak of smallpox among the Indians which, as a matter of self-protection as well as for humanitarian reasons, engrossed the care and attention of the American Chief Engineer and his surgeon all summer.

The Survey is giving special attention to the publications, for the use of engineers, of the geographic coördinates, the descriptions of the trigonometric stations, and the leveling and magnetic results. The daily mail at the Survey office impresses one with the widespread and increasing demand for this information, and taxes the ability of the office to keep pace with it. Each division is in charge of an expert and the result is that the methods of the Survey compel the close attention and study of other nations and often serve as a model for them.

DISCUSSION.

M. B. Snyder (visitor).—This seems to be a case where it is hardly possible to see the woods for the trees. The details which the head of the Geodetic Survey has been reviewing for us appear too manifold for just discussion, and it is almost impossible for us to comprehend the vast magnitude of the work of the Survey.

I think it is desirable to look at the woods, that is, to look at the great results which have been accomplished by this American institution, and to keep in mind that there is a possibility even in America, with all the difficulties with which we have to contend, of developing genuine science in governmental institutions. I have had a little experience in attempting to get the interest of Congressmen and Senators in a scientific subject, particularly in our enterprise of the Electrical Congress of 1884, and only those who have made such attempts can appreciate what the efforts mean. I think that as Americans we ought to sympathize with one another in the difficulties which all of us face in doing any scientific work, in the American atmosphere, and particularly sympathize with those who are trying to develop science in connection with governmental enterprise. I know that all who are attempting to do scientific work throughout the country

are looking with great interest toward those who are trying to develop in governmental institutions the strong scientific features which will tend to make our American civilization stable.

Professor Tittmann has been giving a brief account of the vast enterprises over which he presides, and I think we should extend our sympathy, and at the same time our hearty congratulations to him and his co-workers for such high effort toward making the United States notable, not for its "spread-eagleism," but for its scientific enterprise.

E. L. Ingram (member).—In 1891–95 I had the laying-out of about 500 miles of the boundary line between the United States and Mexico, from El Paso to the Pacific Ocean, and, although the country we passed through was bad enough, it was not as bad as the country we have seen on the screen to-night. From a technical point of view, I think the most interesting question with which we were concerned was, What is meant by a straight line on a spheroid? A straight line on a sphere is understood by surveyors to mean the arc of a great circle, but this definition is not applicable to a spheroid, which for practical purposes may be regarded as the shape of the earth. A line 500 miles long may vary in location as much as 10 feet at the center, according to the definition adopted for a straight line. The boundary which we were locating had two lines, one 260 miles long and one 150 miles long, which by treaty were required to be straight. I think we spent about three days in discussion and computation on this phase of the subject, and then found that as far as our lines were concerned the possible variation under any accepted definition of a straight line would be less than a single inch, which was much less than the probable errors of location.

There was one point brought out by Professors Tittmann and Doolittle, which is of considerable interest to geodesists, and that is the question of the variation of latitude. The reports that appear in the scientific journals from time to time are more or less indefinite and obscure. The general sense of these reports seems to be that the poles of the earth are not fixed, but perform what may be called a revolution around a mean point in an average period of about 425 days, with a radius varying from 0.16 seconds (16.3 feet) to 0.36 seconds (36.3 feet), the path of the moving poles being irregular and different on each successive revolution. The result of the constant shifting of the poles not only causes continual variation in the latitude of any given point, but all latitudes, longitudes, and azimuths become variable quantities, subject to an unceasing oscillation about their mean value. I would like to ask Professors Tittmann and Doolittle how far my statement of the case is correct, in the light of present knowledge, and what additional information may be available.

C. L. Doolittle (visitor).—I was connected with the survey of the northern boundary, from the Lake of the Woods to the Rocky Mountains, from 1873 to 1874–75, when the work was done, and much of what Prof. Tittmann has been telling us is quite familiar to me as I have been over the ground myself. The work the Coast Survey is doing now is to restore the monuments of the boundary as we marked it.

I was much interested in the accuracy with which those monuments could be placed. In the determination of the parallel we made observations for latitude, which fixed a point on this parallel. We then ran the tangent, as we called it, to the next station, 20 miles or so distant. The offsets from the tangent

to the boundary adopted were the combination of the curvature of the parallel with the amount of station error, the latter due to local deviations of the plumb line. You never get a plumb line which will be an exact normal to the surface. There will always be a deviation; we never found a case where there was not considerable deviation. This question of variation of latitude, which Professor Tittmann has been talking about, and which I have been working on for the last twenty-five or thirty years, will give us a range from 50 to 60 feet, and on this account, if I determine the latitude today, and I determine it six or seven months from now with absolute precision, I would likely get a point of 40 or 50, or in extreme cases, 60 feet from the point I occupied before. Some one has said in regard to the 49th parallel that there is a strip of 50 or 60 feet wide that belongs alternately to one country and the other. In other words, the boundary varies 50 or 60 feet.

I think Professor Ingram's question can be readily answered, for I would say that we know very little about it. We know what is taking place, but as to the cause of it, and as for formulating a law for it, if we could predict what is going to happen ten years from now this might be possible, but we know very well we cannot. We thought some years ago that we were in line with the direct solution of this problem. The theory is very definite, and was worked out long ago by Prof. Euler, who established, theoretically, that there ought to be such a variation, and, assuming the earth to be a rigid body, he found a period of about 10 months; efforts were made for a long time to discover such a period or such a variation, but all of the attempts, as far as I know, were based on the supposition that the period was 10 months.

Well, different ones had more or less to do with it and I think I was a sort of pioneer in that direction myself. Instead of working at this theory I tried, by observation, to find out what was taking place. Professor Chandler, of Cambridge, who was more prominently connected with it in those days than anybody else, published with a good deal of confidence a conclusion that he had reached as a result of the analysis of many thousands of observations made at various places, that the variation had a period of about 14 months instead of 10 months, but that superimposed on that was another period of one year, and that the combination of the two produced the changes and irregularities that Professor Ingram referred to. This hypothesis can be made to fit the observations for a considerable period but it does not follow on to predict what is going to happen. You can take observations and fit such a curve to them but, if exterpolated a year or two ahead, it will not fit the observations at all. At present it is impossible to predict the position of the actual pole in regard to the mean pole. It appears to depend, to some extent at least, on meteorological causes, and if that really has much to do with it, it would be a proposition on the same order of difficulty as predicting the weather for long periods ahead. When we are able to solve this problem perhaps we may attack this latitude problem with some hope of success.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Regular Meeting, October 18, 1911.—Present: President Hess, Vice-President Hutchinson, Directors Mebus, Swaab, Wood, Kerrick, Worley, Develin, Gilpin, Vogleson, Haldeman, the Secretary and the Treasurer.

It was ordered that a special memorial of our late President, James Christie, be reprinted from the Proceedings of the Club, and specially bound. The execution of this was left to the Committee on Publication.

The committee on the regulation of smoking in the meeting-room presented a progress report.

The Secretary presented a report of the financial condition of the Club, which showed a gain in operating expenses for the first nine months of the year of $828.79.

The matters of depreciation and insurance were discussed, and were referred to the Finance Committee, to report at the next meeting of the Board of Directors.

It was ordered that a Committee be appointed to prepare a method of procedure to be followed in regard to delinquent accounts.

It was moved and carried that the credit of all members of the Club be absolutely limited to $50.00, except that the room rent of permanent residents of the Club house be not included in this amount.

Mr. Worley presented correspondence received from Mr. Hering, making certain complaints in the management of the house.

It was moved and carried that the House Committee be informed that it was the sense of the meeting that monthly rates be charged for rooms when the occupancy exceeded a month.

Mr. C. A. Albrecht's resignation was accepted, as of July 1, 1911, provided his account prior to that time be settled in full.

The following resignations were also read and accepted: Walter C. Kennedy, John Reilly, Jr., John M. Weiss, and R. C. Williams, Jr.

It was ordered that a sum not exceeding $125.00 be appropriated to the Entertainment Committee to give a Club Smoker, on November 11, 1911.

It was ordered that the regular meetings of the Board in the future be held on the Thursday preceding the second meeting of the Club in each month.

Regular Meeting, November 16, 1911.—Present: President Hess, Vice-Presidents Plack and Hutchinson, Directors Swaab, Wood, Worley, Cooke, Develin, Gilpin, Vogleson, Haldeman, the Secretary and the Treasurer.

The Secretary presented a statement of the financial condition of the Club, which showed a gain in operating expenses for the first ten months of the year of $655.90.

The matter of delinquent accounts was discussed at some length.

Mr. F. H. Stier was added to the Committee on Delinquent Accounts, making

the Committee to consist of Messrs. A. C. Wood, S. M. Swaab, F. K. Worley, Henry Hess, and F. H. Stier.

The Finance Committee, as ordered at the last meeting of the Board, reported on depreciation, and, following this, it was ordered that the property be carried on the books at the full replacement value, after charging off an amount of $131.15 for depreciation for the current year.

It was ordered that the Chairman of the Meeting Committee be instructed to notify the steward, on the day of each regular Club meeting, as to the number of luncheons expected to be served. The House Committee was ordered to report, at the next meeting of the Board, on the matter of placing drawing tables and reading lights in each of the bedrooms.

It was moved and carried that the small dining-room may, in the future, be reserved for small meetings upon the request of any member of the Club, provided such reservation does not conflict either with the lunch hour or the meetings of the Board. Application for the use of this room, and allotment to be made by the clerk at the desk, and no charge to be made for this service.

Regular Meeting, December 21, 1911.—Present: President Hess, Vice-Presidents Hewitt and Plack, Directors Mebus, Swaab, Halstead, Kerrick, Gilpin, Haldeman, the Secretary, and the Treasurer.

The Secretary presented a statement of the financial condition of the Club, which showed a gain in operating expenses for the first eleven months of $1961.64, and a net cash gain of $344.54.

The Entertainment Committee presented a report on the Club Smoker held November 11th.

The method of retirement of the building fund notes was discussed and referred to the Finance Committee for report at the next Board meeting.

It was moved and carried that the President and Treasurer be authorized to negotiate a thirty-day loan of $1500.00.

The matter of delinquent accounts was discussed, and it was ordered that all these accounts be carried over until the January meeting of the Board.

It was moved and carried that the Executive Committee be instructed to draft a new set of rules for the government of the Board of Directors, to supersede those adopted January 15, 1902.

Following a recommendation of the Membership Committee, the following Juniors were advanced in grade: Charles W. Bell, Richard P. Brown, Lionel F. Levy, and Louis J. F. Moore, to Active membership, and D. L. Britten, Thomas H. Griest, and Charles F. Thacher, Jr., to Associate membership.

The following resignations were read and accepted: Thomas G. Janvier, Charles F. Schaeffer, H. S. Hayward, Louis S. Bruner, S. A. Bockius, Paul R. Loos, H. P. Hammond.

Mr. David Halstead was appointed Chairman of a Committee to be appointed to advance suggestions leading to a more active use of the Club house.

Mr. W. L. Plack was authorized to expend an amount, not exceeding $50.00, on repairs to the billiard tables.

The matter of holding "open house" on New Year's day was discussed, and it was ordered that this entertainment be not given this year.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, September 16, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 62 members and visitors in attendance. The minutes of the Regular Meeting, of June 3rd, were approved as printed in abstract.

The Committee on Nominations, viz., Wm. Easby, Jr., chairman; H. H. Quimby, J. C. Wagner, W. B. Riegner, Herbert Rice, H. E. Ehlers and Wm. C. Kerr, proposed by the Board of Directors, at the meeting of the Club on June 3rd, was approved.

A Memorial of the late James Christie, prepared by Dr. Henry Leffmann and Mr. John C. Trautwine, Jr., was presented by Dr. Leffmann.

It was announced that at the Regular Meeting of the Board of Directors, held September 5th, Mr. Henry Hess had been elected President of the Club, Mr. Edward S. Hutchinson elected as first Vice-President, and Mr. B. A. Haldeman member of the Board, all these elections for terms to expire February, 1912.

Dr. David S. Flynn, Sanitary Expert of the Catskill Aqueduct Commission, presented the paper of the evening, entitled, "The Sanitary Supervision of the Catskill Aqueduct," which was discussed by Messrs. E. S. Hutchinson, H. C. Berry, Henry Leffmann, Robert Schmitz, S. M. Swaab, and others.

Upon motion of Dr. Leffmann, a vote of thanks was extended to Dr. Flynn.

Business Meeting, October 7, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 92 members and visitors in attendance. The minutes of the Business Meeting, of September 16th, were approved as printed in abstract.

Following a report of the Tellers, the President declared the following elected to membership in the Club: Associate, Charles Wilke, Junior, William L. Brown and Walter S. Crowell.

Mr. C. J. Ramsburg presented the paper of the evening, entitled, "Gas Production with Special Reference to the Manufacture and Distribution of Illuminating Gas in Cities," which was discussed by Messrs. H. H. Quimby, Robert Schmitz, W. P. Dallett, Carl Hering, Henry Leffmann, John C. Trautwine, Jr., Harrison Souder, and others.

Upon motion of Mr. E. M. Evans, a vote of thanks was extended to Mr. Ramsburg.

Regular Meeting, October 21, 1911.—The meeting was called to order by Vice-President Hutchinson, at 8.25 p. m., with 189 members and visitors in attendance. The minutes of the Business Meeting, of October 7th, were approved as printed in abstract.

Mr. John W. Ledoux presented the paper of the evening, entitled, "The Failure of the Austin Dam," which was discussed by Messrs. Edwin F. Smith,

Carl P. Birkinbine, John C. Trautwine, Jr., J. E. Gibson, George S. Webster, Manton E. Hibbs, and others.

Following the discussion, it was moved and carried that a committee of the meeting be appointed by the Chair to consider the discussion relating to the subject of Governmental Control of the Construction of Dams in Pennsylvania, and to report at the next business meeting of the Club. The Chair then appointed the following Committee: Edwin F. Smith, Chairman; John C. Trautwine, Jr., John W. Ledoux.

Business Meeting, November 4, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 102 members and visitors in attendance. The minutes of the Regular Meeting, of October 21st, were approved as printed in abstract. The Committee on Governmental Control of the Construction of Dams in Pennsylvania presented a progress report, and stated that it would probably present its final report at the next meeting of the Club. Mr. John Birkinbine spoke briefly on this subject.

Prof. O. H. Tittmann, Superintendent of the Coast and Geodetic Survey, presented the paper of the evening, entitled, "The Present Activities and Progress of the Coast and Geodetic Survey," which was discussed by Mr. E. M. Nichols, Prof. Doolittle, Prof. Snyder, Mr. John C. Trautwine, Jr., Prof. Ingram, and others.

It was moved by Mr. Trautwine and carried that, in thanking Prof. Tittmann for his interesting paper, a message of appreciation and congratulation be given to him and his associates for the advances made in the work of the survey.

Business Meeting, November 18, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 72 members and visitors in attendance. The minutes of the Business Meeting, of November 4th, were approved as printed in abstract.

The Committee on Governmental Control of the Construction of Dams in Pennsylvania presented both a majority and a minority report. Following a brief discussion, it was ordered that both the discussion and the action upon these reports be laid over to a special meeting of the Club, to be held on Saturday December 9th.

The Committee on Nominations presented the following nominations for officers of the Club for the year 1912: President, Henry Hess; Vice-President, Charles F. Mebus; Secretary, W. P. Taylor; Treasurer, F. H. Stier; Directors, H. C. Berry, B. A. Haldeman, S. M. Swaab, D. R. Yarnall.

Mr. J. C. Meem presented the paper of the evening, entitled, "The Theory of Earth Pressure," which was discussed by Mr. H. H. Quimby, Dr. H. M. Chance, and others.

Upon motion of Dr. Chance, a vote of thanks was extended to Mr. Meem.

Business Meeting, December 2, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 64 members and visitors in attendance. The minutes of the Business Meeting, of November 18th, were approved as printed in abstract.

Following a report of the Tellers, the President declared the following elected

to membership: Active, John B. Dilworth, John J. Gartland, Jr.; Associate, Jared S. Kenyon: Junior, Ernest Hagenlocher.

Mr. Arthur P. Davis, Chief Engineer of the U. S. Reclamation Service, presented the paper of the evening, entitled, "Reclamation Engineering in Russian Turkestan," which was followed by a short discussion by Messrs. W. C. Furber, E. M. Nichols, and others.

Upon motion of Mr. Nichols, a vote of thanks was extended to Mr. Davis.

Special Meeting, December 9, 1911.—The meeting was called to order by Vice-President Plack, at 8.30 p. m., with 48 members and visitors in attendance. The majority and minority reports of the Committee on Governmental Control of the Construction of Dams in Pennsylvania were brought up for consideration, and, following a discussion in which the following took part—Edwin F. Smith, J. C. Trautwine, Jr., J. W. Ledoux, J. C. Parker, John Birkinbine, Henry Leffmann, J. E. Gibson, Manton E. Hibbs, G. S. Cheyney, H. H. Quimby, J. W. Hunter, and others—the following resolution was adopted:

Whereas, the failure of the Bayliss Pulp and Paper Company's Dam on Freeman's Creek, above Austin, Pa., on September 30, 1911, calls attention to the importance of insuring the safety of such structures where failure is a serious menace to human life. Therefore, be it

Resolved, that such structures should be entrusted only to engineers of ability and experience, who should have constant supervision of every phase of the construction; and, be it further

Resolved, that the Governor of the State is, therefore, requested to call together a special Commission of competent engineers, aided by legal talent, to frame comprehensive regulations providing for the creation of a State Department of Public Works, to be composed of bureaus so constituted that their combined jurisdictions should cover not only the construction of dams but all other engineering contingencies likely to arise in the near future.

It was further ordered that a copy of this resolution be sent to the Governor of Pennsylvania.

Business Meeting, December 16, 1911.—The meeting was called to order by President Hess, at 8.30 p. m., with 76 members and visitors in attendance. The minutes of the Business Meeting, of December 2nd, were approved as printed in abstract.

Mr. Robert Schmitz presented the following resolution for discussion at the next meeting of the Club: "That the other engineering societies and clubs in this State be asked to consider resolutions on the governmental control of engineering structures, and, if possible, that their coöperation be obtained in securing legislation in this matter."

Prof. Gardner S. Williams presented the paper of the evening, entitled, "The Water Power Plant of the City of Sturgis, Michigan," which was discussed by Messrs. J. C. Trautwine, Jr., H. M. Chance, J. E. Gibson, Robert Schmitz, and others.

On motion of Mr. Webb, a vote of thanks was extended to Prof. Williams for his interesting paper.

THE ENGINEERS' CLUB OF PHILADELPHIA

1317 Spruce Street

OFFICERS FOR 1911

President
HENRY HESS

Vice-Presidents

Term Expires 1912
EDWARD S. HUTCHINSON

Term Expires 1913
CHARLES HEWITT

Term Expires 1914
W. L. PLACK

Secretary
W. P. TAYLOR

Treasurer
F. H. STIER

Directors

Term Expires 1912	*Term Expires 1913*	*Term Expires 1914*
B. A. HALDEMAN	DAVID HALSTEAD	ST. GEORGE H. COOKE
CHARLES F. MEBUS	E. J. KERRICK	R. G. DEVELIN
S. M. SWAAB	PERCY H. WILSON	RICHARD GILPIN
A. C. WOOD	F. K. WORLEY	J. A. VOGLESON

STANDING COMMITTEES OF BOARD OF DIRECTORS

House—F. K. Worley, David Halstead, W. L. Plack, Richard Gilpin, W. P. Taylor.

Meetings—S. M. Swaab, Chas. Hewitt, W. P. Taylor, J. A. Vogleson.

Membership—Chas. Hewitt, Chas. F. Mebus, R. G. Develin.

Finance—J. A. Vogleson, Henry Hess, Edward S. Hutchinson.

Publication—Chas. F. Mebus, St. George H. Cooke, A. C. Wood.

Library—W. L. Plack, Richard Gilpin, E. J. Kerrick, Percy H. Wilson.

Publicity—Henry Hess, David Halstead, F. H. Stier.

Advertising—R. G. Develin, F. H. Stier, Percy H. Wilson.

MEETINGS

Annual Meeting—1st Saturday of February, at 8.15 P. M.

Stated Meetings—1st and 3d Saturdays of each month, at 8.15 P. M., except between the fourteenth days of June and September.

Business Meetings—When required by the By-Laws, when ordered by the President or Board of Directors, or on the written request of twenty-five Voting Members of the Club.

The Board of Directors meets on or before the 3d Saturday of each month, except June, July and August.

PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. XXIX. APRIL, 1912. No. 2

PRESIDENTIAL ADDRESS.

OSTWALD'S ENERGETICS AS A MORAL FORCE AND LAW, AND IVES' COLORIMETER AND COLOR PHOTOGRAPHY.

HENRY HESS.

Annual Meeting, February 13, 1912.

Introductory.—It is usual that your President begin his year with an address pertaining more or less closely to the affairs of your Club. But you are familiar with these from their quite thorough discussion in connection with the adoption of certain changes in its constitution —possibly certain changes that were advocated, discussed, and not adopted made you still more familiar with your Club's difficulties and the problems confronting your chosen administrators. I shall, therefore, touch but briefly on this subject.

This Club is not simply a club: it is far more a technical society than the social organization usually termed a "club." It is, moreover, a very active technical body. If proof were needed, you need but consult the committees on meetings of our large national technical societies; one and all will assure you that it is a most difficult thing to get good material for two meetings a year; yet you are able to assemble a fair audience twice a month, not infrequently even to tax the resources of this auditorium. Much credit is due your very efficient Chairman of the Committee on Meetings, Mr. Swaab, but not even he could secure so active attendance were the body of our membership itself not far more representative than mere numbers indicate.

The papers presented during the past year have covered a wide range; they have been read not only by members of your Club, but men of high standing in the nation and of international renown have gladly availed themselves of the opportunity of securing so appreciative, able, and influential an audience.

Occasionally a member would like to hear about a subject somewhat more closely akin to the problems presented in his particular specialty; his suggestions are more than welcome; they are eagerly solicited, and, if he should be too modest or too self-depreciative himself to present a paper, he can suggest some one he thinks would have something interesting to say, and can then himself add to the interest of the occasion by an active participation in the discussion.

But this very dual nature of this organization, this duality of social club and technical society, brings in its own difficulties. We have a house to maintain, and the maintenance calls for means. We have but one chief source of income—that from dues. These dues are low—far lower than those of any organization giving its members what your Club does. Nor is it desirable to raise these dues, as that would press hardly on a considerable portion of our membership that, with the modesty or distaste to push itself in the marts of the world, or from the largely inherent tendency of the working engineer to do, rather than to get, is not overburdened with pelf.

We have a membership around the 600 mark; the income barely suffices to keep things moving, and allows laying by of but little for the future; frequently, even, your officers have to pledge their credit when returns are not made so promptly as they should be, while liabilities must be met. Two hundred new members would provide an income sufficient to relieve the situation; 400 would spell comparative affluence. It is not yet so long since the year was new that the suggestion for a New Year's resolution is out of place; it might even be that a New Year's resolution, a trifle belated, would escape the usual fate of a prompt forgetting. Why will not each one of you register a vow with yourself to bring in at least one new member before the month is out? And a second one next month? I believe I may venture to assure you that your most self-sacrificing and hard-working Treasurer, Mr. Stier, would be pleased to place on the bulletin board, engrossed, if you like, the name of that member who has succeeded in bringing home to the greatest number of new men that, by joining you, they have performed a civic duty, while benefiting themselves.

It is a source of much gratification to me, and of still greater pride, to find myself occupying the presidency of this Club, through the suffrage and at the call of so representative a body of men, recruited from every branch of that ablest and most self-sacrificing and hard-working and hard-worked profession of engineering. I should like to express that appreciation and thank you in fitting periods, but, though I may be able to talk long and much on various things, words fail where my feelings are most deeply concerned. Yet it was with regret that I first found myself in the Chair some months ago, to fill out the unexpired term of our late revered and lamented President, Mr. Christie. Twice you called on Mr. Christie to serve you, and while that honored him, yet you, or any other body, honored itself far more in being able to secure the response of a man such as he to its call.

Ostwald's Energetics and Cultural History.

Instead of regaling or wearying you with a recital of my own views or work, I crave your indulgence in laying before you some matter taken from a recent work in German by that dean of our profession, Dr. Wilhelm Ostwald, "Die Forderung des Tages"—"The Demand of the Day." It is true that Dr. Ostwald is more generally known as a chemist, creating and marking an epoch, and as an inspiring teacher, and that he would, therefore, not generally be considered a dean of engineers, yet true engineering in its widest sense was a decidedly fundamental activity of his. The particular essay that so profoundly impressed me that I wished to gain your appreciation by bringing it before you was Ostwald's lecture on "Energetics and Cultural History." Were its author a writer aspiring to the older distinction of the classic culture, I should hesitate to thus crib, but engineers are broad-minded, and desire only to give the widest spread to their discoveries and teachings; let that be my apology.

Ostwald defines energetics as that scientific conception which considers the physical idea of energy as the one which, for the time being, presents the most exact gathering of physico-chemical facts and laws. Dr. Grechen pointed out that energetics is first a theory of physical phenomena, and that a connection of its results and methods of thought with the problems of the higher mental life is not immediately apparent. Energy, as the term is today scientifically defined, has but a loose connection with the moral quality of the

same name. To the engineer, energy is a physically measurable quantity, best known to us as mechanical work. As chemistry teaches that coal, graphite, and carbon all represent the same substance, carbon, insofar as each of these may be changed into the other, so does physics teach that mechanical work may be changed into heat, light, electricity, chemical effects, etc. As impossible as it is to increase or decrease a given quantity of carbon by the most complicated transformations, so impossible is it to increase or decrease a given amount of work by the most intricate transformations. For both there rules the law of conservation. That which we can neither create nor destroy we call a substance; thus the chemical elements have the character of substances, as have also work and its transformation products. These latter are given the common term "energy," while the science of the laws governing the manifold transformation of energy is "energetics."

Prefacing that this is all well known, Ostwald answers the question for the reason of this repetition by the statement that these laws not only regulate, but even make possible, our very existence. Life is based on a continual change of energy in our body; with the instant of interruption of this change death ensues. But not only individual life, but all social life also, is directly dominated by the laws of energy. That a speaker may appear before you is due to the energy of some means of conveyance; that you hear a speaker is due to the energy conveyed from his vocal cords to you in soundwaves; that you understand a speaker is based on the energy of your own mental activity. That is why we must, first of all, be practicers of energetics, long before we may choose any other view of the world—*why nothing may happen without the participation of energy in various forms!*

While the fact of energy is an every-day one, with the term not nearly so well known, the condition is exactly reversed as to culture. The word is generally familiar, but an agreement between any two or three educated people as to a definition will be hard to secure. There are many definitions of this term which it would seem impossible to give a common denominator. But the usefulness of energetics will show itself in its ability to embrace all of the many sides of the cultural problem. All life, individual as well as social, utilizes those forms of energy that it comes into contact with for its own purposes by suitably transforming them. The result of this transformation may be great or little, as compared with the energy expended,

much as a skilled artisan may, in a given time, do tenfold the work of an unskilled one. Ostwald makes the extremely significant assertion that the *measure of culture is the efficiency of transformation of raw energies to human purposes.* As the teachings of the schools have robbed most of us of an untrammeled vision, an explanation and a justification are in order:

All ancient culture was based on the existence of slavery. Only through it could a few acquire that leisure and the means essential to free scientific pursuits. This resulted in the involuntary equation of possession of slaves with high mentality, and the despising of all technical work as fit only for slaves. But the ancients themselves disproved this original hypothesis, since among the chief furtherers of culture there were found more and more slaves and freed men, because culture is based on *work*, technical as well as mental; between these two also the difference grows increasingly less.

If we can imagine ourselves back into the probable initial condition of human development, we see before our mental vision a being that is not superior to its surroundings by either strength, speed, invulnerability of covering, or otherwise advantageously fitted for the fight for existence; it is also not guarded against dying out by such protection as is found in a particularly simple organization or by great fecundity. *A single quality differentiates this being from others, that of increasingly freeing itself from the influence of changing conditions of existence by the formation of new, or the intentional retention of old, beneficial conditions.* It is this quality that finally gave to this weakly and poorly fecund race the dominance of the earth. Wherein lies the essence of this advance? What is the basic principle involved? Ostwald answers his question that *man learned to apply one transformer of energy after another,* using and bending to his purposes first the native energy of his own muscles, then that of other men (slaves), of animals, of plants, and finally the anorganic energies (wind, ground wealth, water power). The *possession of energy* in the sense of physical energy or the generalized idea of work *means the domination of the world.* If, today, more than ever before, the ownership of mobile capital carries with it this domination, it is because capital represents the most concentrated and most readily transformable form of energy.

It is often said that man acquired the domination of the world by his reason, and that reason carries with it the concentration of great power in the individual. This is true so long as reason is directed

to acquisition of energy and its purposeful employment. Chess certainly does call for the exercise of considerable reason, and a champion certainly does develop much reasoning power when playing a game with a worthy opponent. But this is not directed to the energy problem, and is, therefore, foreign to culture; the latter would probably be greater, rather than less, did nobody play chess.

When some primitive man first found that using a broken tree limb enabled him to strike an opponent, animal or man, before that opponent could close with him, the first step was taken in the path of purposeful transformation of energy.

Purely mathematically the inclusion of the weapon (tool) did not permit the full application at the intended place of the entire muscular energy used. But the lesser absolute amount was compensated for by a more efficient application. Whereas the forefather of this inventor had to pay for each bear choked with his bare hands by wounds and days or weeks of inability to work, the cudgel wielder could kill his bear without being even scratched, and saved himself the days of nursing. He was, therefore, able, in the same time and with the expenditure of the same amount of energy, to kill far more bears than his *brave* ancestor, who did not know how to transform his muscular energy by use of the cudgel.

The same may be said of each advance in culture; that is, either a more useful transformation of personal bodily energy, or the economic utilization of foreign energies for personal account. The first step in this second direction is undoubtedly the utilization of the man power of others, first having learned to direct and form that to one's own will. This brings before us for the first time the remarkable fact that by energy of higher grade lesser energies are dominated, even though the absolute amount of the subjugated far exceed that of the dominant energy. More remarkable still, all uprisings of slaves have ended in fiasco; in other words, all attempts to make absolute energy amount dominate have failed because these raw energies lacked organization. Only from the union of rising classes with ruling classes, where, therefore, the raw energies were organized, did lasting forms result. So it was in the history of the ancient Roman Empire, and so must we read the history of the French Revolution, with its consequences, in which the intelligence and the organizing ability of the upper classes were still needed to make permanent that freedom of the masses acquired by mere brute strength.

Ostwald then develops the same thought through the beginning and progress of the utilization and domination by man of the animal and plant world. The traditional reverence of the mythical discoverer of fire shows that the enormous step in the regular utilization of anorganic energy was felt and realized in prehistoric days. But the period of the extended and systematic utilization of anorganic energy has but begun, and may be counted back over barely a century. It began with the introduction of the steam engine with the nineteenth century, is now passing through a new development period in the utilization of water powers that was first made feasible scientifically by electrotechnics, and will finally have to take up the problem of the utilization of solar energy, that is now but poorly solved by plants with an efficiency of less than 1 per centum.

The older point of view—that of the adherents of the older "classic" education or "culture"—would make the advance of mankind in the technical arts, and the material ease that in turn gave time for the practice of this culture, a result of the culture. This idea is abhorrent to the strict logician, as making a result produce itself. Ostwald has clearly pointed out the logical line of development. Refer back again to the existence of a high classic culture as based on the leisure due to slavery, and then to the almost total loss and extinction of this culture, and its renascence and far wider and more general distribution as a result of the application of mental effect to the despised handiwork and brain work of the technician and scientific worker. The old classic arts had but a hectic existence and an early death, because based on the subjugation of human muscular energy (slavery), much as the consumptive shows a complexion envied by those not recognizing it as a symbol of early decay.

The necessity for this order of development is clear, since the progressive dominance of the other energies to that of the anorganic ones demands an increasing faculty for abstract thinking, which can but be the product of a greatly advanced real culture. That others can work as we do is a thought easily grasped; but that an animal may be trained to work does not fail to astound every child—is, therefore, unexpected. That a piece of wood or coal may work was so far fetched an idea that it required thousands of years before the thought occurred to man. And the law of the conservation of energy, which first permitted a clear view of this vast field, and with that its dominance, is barely sixty-eight years old.

So far the advance of culture has been considered only in its more

narrow technical sense. Is there also a connection with the social and political organization in families, races, and people, with the State and law? At first glance the question of energy would appear to have nothing to do with these matters, and this would be true were it only a question of the law of the conservation of energy. But what purpose do organization, law, state, and the various other social forms of mankind serve, other than the increasingly useful utilization of the available energies? What else is the law but an arrangement which permits each individual to devote his energies to a useful purpose, without having to deflect a portion to defense from predatory neighbors?

Ostwald next follows the development of war and armies from the early mere aggregation of men depending upon their muscular energy, to the defeat and displacement by those first using animal energy (cavalry), to their defeat in turn through the utilization of more concentrated forms of energy, as in gun-powder, and to the change from loose aggregation to the present firm aggregation into a relatively small number of powerful nations, and then draws a parallel with capital.

Simultaneously, another form of energy concentration has developed power as "mobile capital." The energy masses that are today collected in this power exceed by far those concentrated in armies; money is more necessary for war than are soldiers.

As in the beginning of the organization of States, the clans were the real embodiment of concentrated energy, and the life of each State depended upon its ability to weld these clans into larger units without the former continually tending to defect, we are today confronted by capitalistic organizations, with individuals and small unions striving to secure the benefits to themselves. Whereas no State today would tolerate an individual person maintaining at his personal disposition a body of armed men, the State does tolerate the concentration of the infinitely greater might of mobile capital in the hands of the individual, making it possible for him to levy tribute on the entire world. Ostwald here points to the monopolization of petroleum by Rockefeller, to hinder which the President of the United States even does not appear to possess adequate power.*

The condition is about the same as toward the close of the middle ages, when the leaders of the mobile free-lance soldiery were practi-

* This was written in 1909, before the recent settlement (?), by dissolution, of the Standard Oil Company.

cally the rulers. Necessarily, the newer development will have to follow a similar path, as the State must itself, in self-defense, undertake the concentration of capital and thus utilize its resultant immense energies for the best interests of its citizens. It is true that this will necessitate the disappearance of the superstitious fear of the interference of the State with private possessions, a Pandora's gift handed down to us, with a choice collection of others, from the old Roman law.

Concentration of capital in the individual has proved itself to mean the most intense possible conversion of the raw energies (mineral, etc., wealth) that the individual or individualistic group controls, into capital energy, without regard to their rational utilization in the interest of the entire community. The concentration of capital in the hands of the State, carrying with it the control of all of these raw energies, substitutes for their conversion in the selfish interest of the few their utilization in the interest of all. We must not consider the ideal of our development the using up, in the shortest possible time, of our surely limited treasures, but find our pride in satisfying our cultural needs with the least possible using up of our raw energies, and not forget the purpose of our life over its means.

Having grasped the significance of this idea of physical energy, its central relation to the extraneous, economic, and social side of human culture may be granted; but can it be applied also to art and science, these highest blossoms of our culture? The answer does not seem doubtful. Quite aside from this much-debated question of psychic energy, it is clear that art and science must be carried on. To carry them on a bodily organization is necessary, the productivity of which depends upon many circumstances, among which a happy increase of productive ability is of chief importance. But this is possible only if the mental apparatus disposes of sufficient free energy. As an old man, Goethe complained much of the diminishing productivity of his later years; it was clear to him that this could not be forced. He, therefore, did his work in the early morning hours, having found that the lessened energy at his disposal in old age was not sufficient to overcome the distractions of the later day and permit other work. The highest work of genius, as all other work, reduces itself to a transformation of energy. It is merely a form of energy of great rarity and corresponding value into which genius converts the lower forms. Its high value again resides in the fact that it influences other men to the better conversion of their energy. The chemist knows phenomena

of this character as "catalysis": an action that ordinarily takes place slowly, even unnoticeably, is incomparably quickened by the presence of a substance that finally comes out of the reaction itself unchanged and undiminished. That is the action of a work of art on a receptive mind: it does not increase the absolute amount of the existing energies, because energy cannot be created; but it does accelerate the rate conversion of the existing energies, and instead of purposeless dispersion, promotes their working together in harmony toward a valuable end. In this catalytic effect of art Ostwald finds the social value and significance of art; it is not only a purpose, but a means to an immensely valuable end.

The social economic value of science is even plainer by far. There is no such thing as science for its own sake (note the significance from a past master of science)—that would be mere play—no, science exists for human ends. Such phrases as idealism and utilitarianism are handy, not to disprove this statement, but merely to decry it for those without judgment.

Whoever follows science for narrow personal ends, to him she is but a milch cow. The sound-thinking and feeling man will enthusiastically follow science whenever he recognizes and feels its social value, be his branch whichever it may, when he sees that it makes it possible for him to lighten human burdens and increase human joys —in a word: to better mankind's utilization of its free energy. Take the most abstract science, logic. If ever there would seem to be a science so academic that it could be followed only for its own sake, this must be it. But a moment's thought will show that the development of logic may decrease the sum of human errors and so make clear the practical value of this science.

One may ask one's self whether any great amount of human discomfort and useless work may be saved by human endeavor. The true scientist will answer "Yes," and in that answer find the enthusiasm and persistence needed for creative work and real advancement of science. But he who has not this perspective, who does not find this *practical* viewpoint, will but hunt a "job."

Idealism is not a lack of purpose, as those who follow purposeless things would have us believe; on the contrary, it is the most intense knowledge of purpose; but the purpose must be set high enough to merit the name of idealism. And all these high purposes may again be viewed as the delivery of mankind of its burden and the enhancement of its joys. But relief from burden is a diminishing of energy

used for a given purpose, therefore improvement in efficiency, while increase of enjoyment means increased activity of the nobler energies resulting from a freeing of a greater portion of the total energy for that purpose—in the end the same thing. We, therefore, inevitably arrive again and again at the same viewpoint, and must be convinced that we have found a scale for the measurement of every human endeavor.

The law of the conservation of energy, also, was first doubtfully accepted, even denied, but today we know that there is no physical phenomenon which may not be brought into a definite equation on the basis of this law.

Ostwald closes with the enunciation of a new law, deduced through a similar development of ideas that:

The measure of culture is the efficiency of the transformation of raw energies to humanly valuable purposes.

Colorimeter and Color Photography.

Many of those present tonight had the privilege of attending a recent lecture at the Franklin Institute by Professor Nichols, of Cornell, in the course of which there were thrown on the screen some slides showing the difference in the color-value of various illuminants. It occurred to me then that you might be interested in some of the more recent work of one of Philadelphia's renowned former citizens. The name of Ives is known the world over, wherever men of science foregather, as also to the men who practise half-tone printing, color printing, or color photography; in all these fields Mr. Ives was a pioneer who not only blazed the way, but also held aloft a torch to lighten the path ahead for others to follow.

Several years ago I spent an entire afternoon taking color pictures of some most interesting landscape effects of varying mist and sunshine, of a beautiful section of country of intimate nooks and of wide reaches, and in all the richness of our autumnal tints. The plates were Lumière autochromes. In these the color effect is due to dyed starch-grains. On development not a single one came out. Taking this up with the maker's agents brought the matter-of-fact statement that occasionally these starch-grains rotted. I determined to produce plates myself that would not be subject to such annoyance, which seemed easy, as, in fact, the difficulty was rather one of choice between the many possibilities. By delving into the history of the

art and the patent records it developed that the ancients had once more appropriated to themselves the ripest fruits of my inventive genius.

My attorney, who had some indirect connection with Mr. Ives, suggested that I might be interested in some of his later work. I met Mr. Ives and was conquered, and then and there dropped all my work of the merest tyro, to ally myself with a past master.

The first need in dealing with color would seem to be a knowledge of color, and that not merely qualitatively, but also quantitatively As to the first, there is today no serious divergence of views.

Speaking not scientifically, but as a layman, light is visualized energy in wave-like motion, the wave-lengths lying between certain limits. Different wave-lengths produce different sensations in the eye and brain, and these are known popularly as color. There are infinite gradations of wave-lengths, and, therefore, of color, and while some eyes are sensitive to a far greater range than others, the perception at one end is generally referred to as violet, and at the other end as red. When all these many different wave-lengths simultaneously reach the eye, we are accustomed to speak of the result as white. A certain mixture of selected wave-lengths is recognized by the eye as a certain color. It is usual to speak of some color as made up of various other colors, which latter are sometimes designated as primary colors. Strictly, there can be no such things as primary colors. Nevertheless, from the layman's and a practical standpoint, this conception is useful and sufficiently exact, since by the suitable mixing of three shades of red, blue violet, and green, practically every color from almost pure white through the entire range can be produced to the satisfaction of the most sensitive eye. Black is impossible because black is not a color, but the total absence of light, whereas color is the sensation produced in the eye by light. White, being the perfect mixture of all wave-lengths giving light, it follows that other colors are produced by the abstraction or suppression of certain wave-lengths, those allowed to reach the eye producing a corresponding color sensation.

Mr. Ives' work in three-color printing, in the development of his "Chromscope," an instrument for the stereoscopic viewing of monochrome transparencies in color, and his later work in direct color photography, made necessary definite knowledge of just those shades of the primary red, blue violet, and green that would give white and other colors at their purest; that meant an ability to

measure color quantitatively. This led Mr. Ives to the development of the colorimeter, Figs. 1, 2, and 3. This is a simple apparatus into which green, red, and blue-violet of standard tints are placed and allowed to reach the eye through apertures, Fig. 3, G, R, B, so proportioned that only such relative amounts can reach it as combine to give the sensation of white. The three slits viewed individually appear as bands of green, red, and blue violet of different widths.

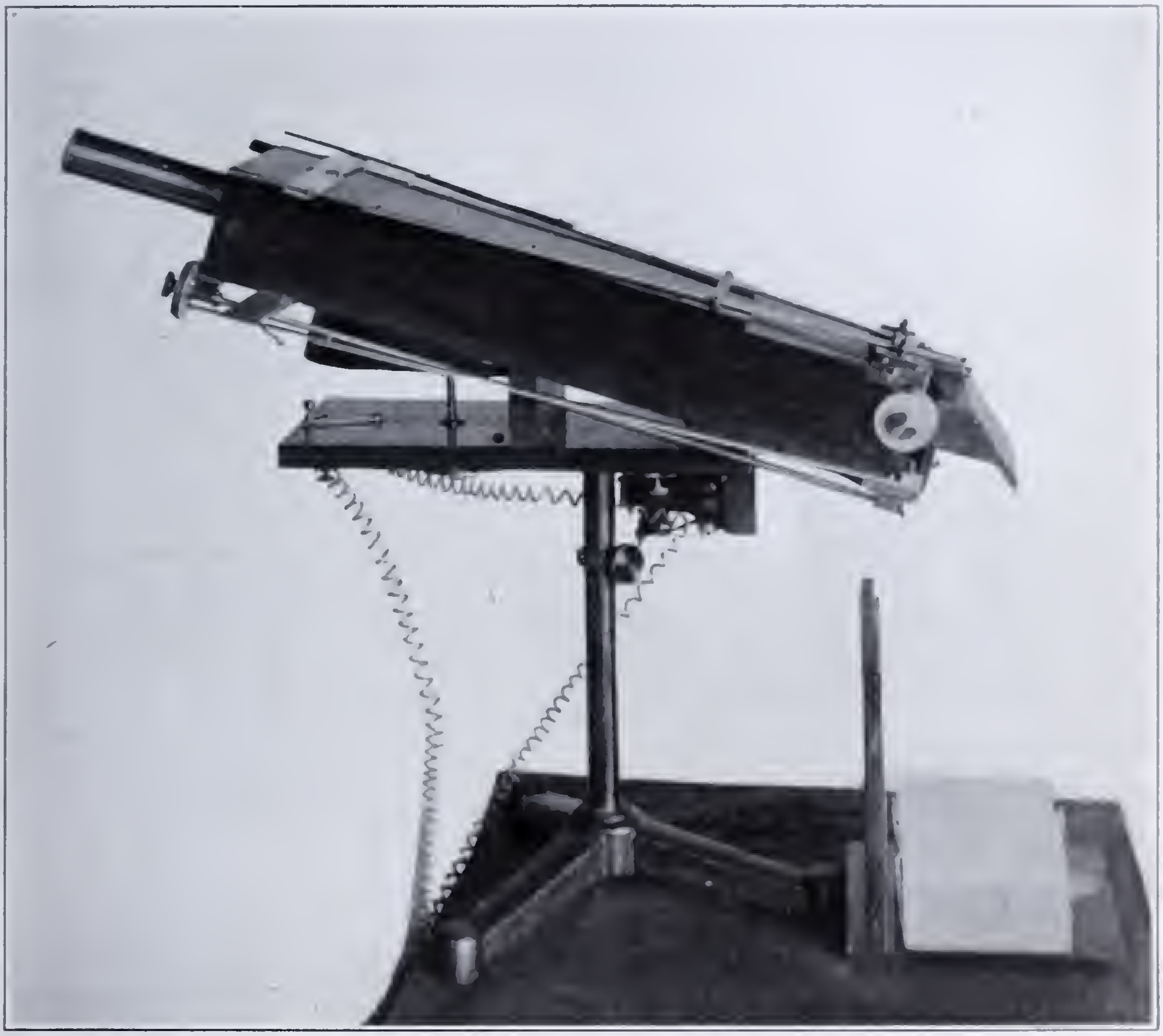

Fig. 1.

A system of rotating lenses, A, Fig. 2, is interposed in such way that only one color is visible at one time; but the three colors are so rapidly brought into the eye in succession by the rotating lenses that the eye, not being fast enough to recognize each separately, realizes merely their composite effect—white. Through a second aperture, D, Fig. 3, the eye views simultaneously a field of standard white—the

purest obtainable. The arrangement is such that half the field is this standard white and the other half that due to the combined colors. There is also an adjustment for the standard white viewing slit to give uniform illumination to this and the combination field. If,

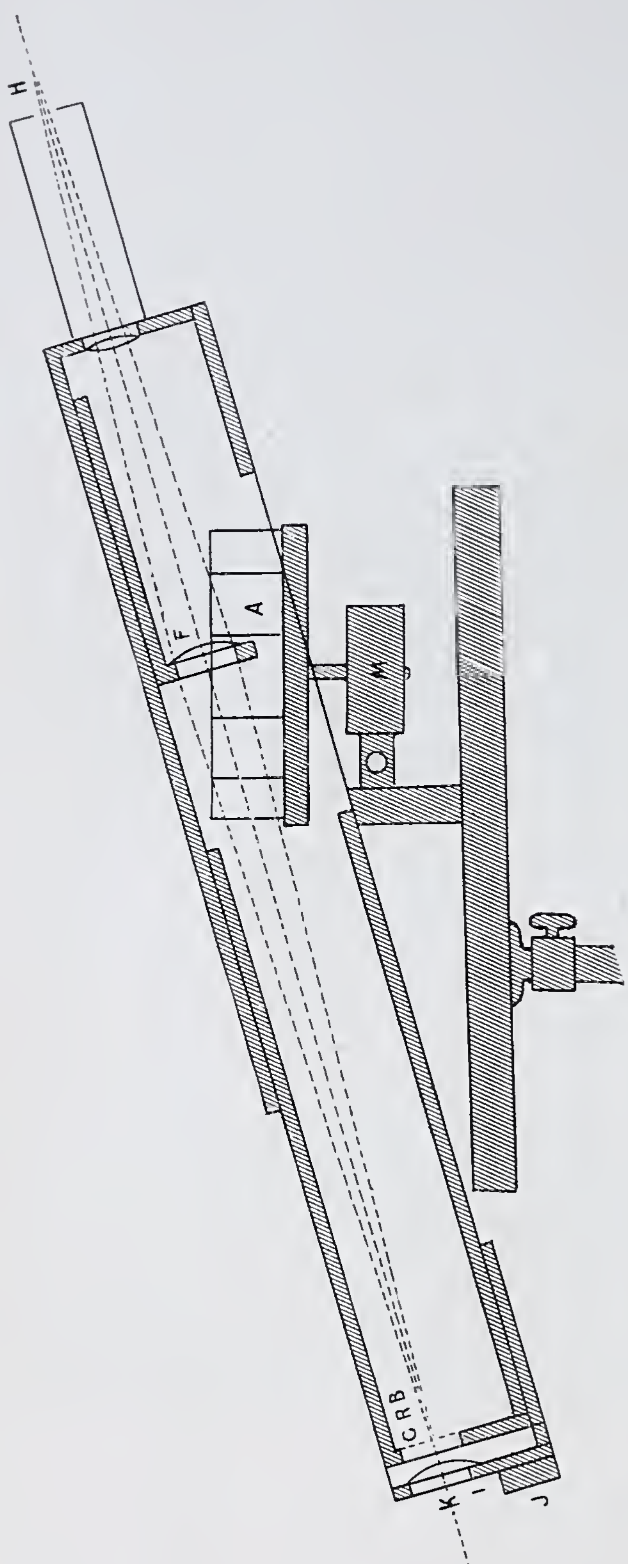

Fig. 2.

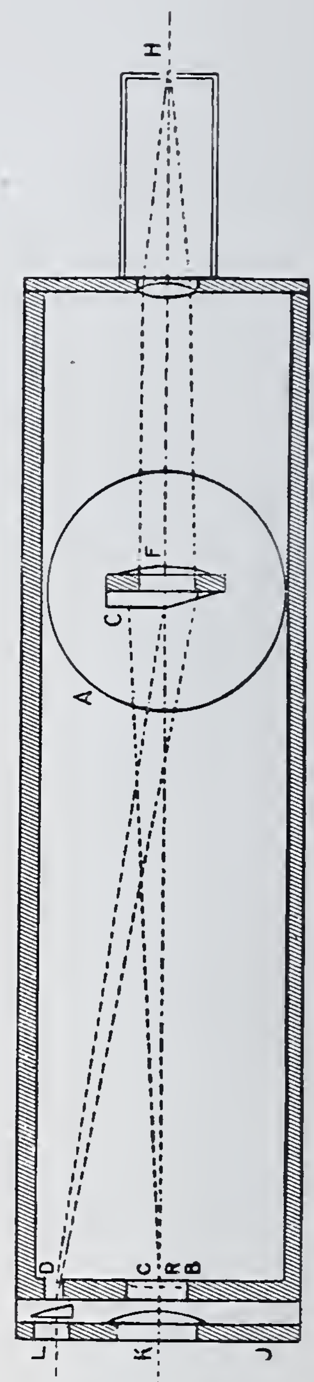

Fig. 3.

now, a color is to be measured that is made to replace the field of standard white, the widths of the red, blue violet, and green slits are then regulated until the eye can see no difference in the field. Even a very slight lack of matching is very noticeable. The sensi-

tiveness of this method is clear from the fact that one one-hundredth part of slit width in one color makes a perceptible change. It is thus possible for a dealer in Philadelphia to tell his dyer in Paris that he wants a certain silk dyed to 50 red, 30 blue, 81 green, and,

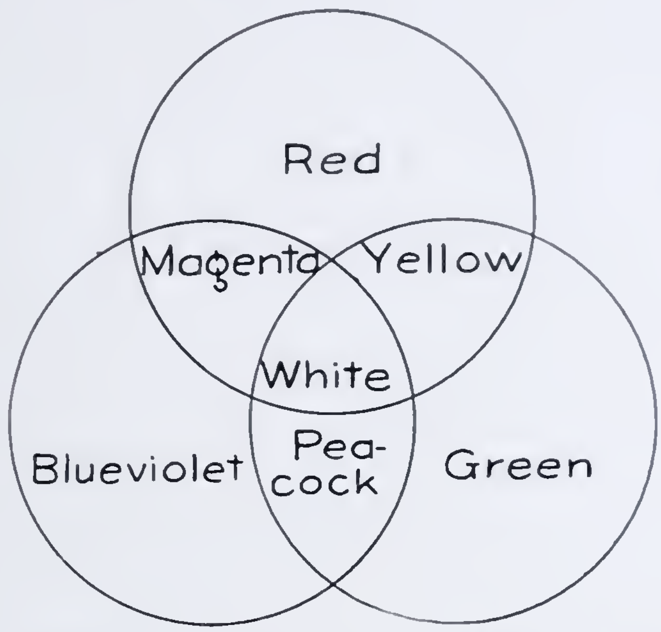

FIG. 4.—Primary Color Mixtures.

if both have an Ives colorimeter, to get an absolute match with greater certainty than by any exchange of samples and the usual reliance on the eye.

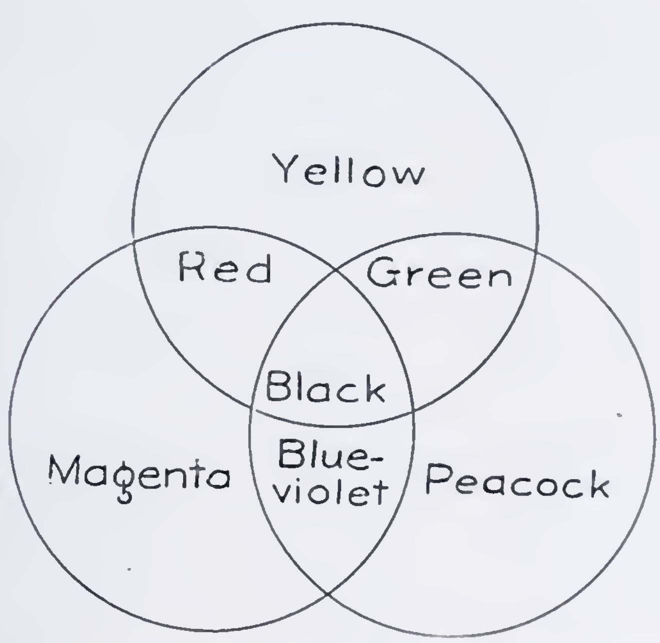

FIG. 5.—Secondary Color Mixtures.

The principle of color mixture is shown by Figs. 4 and 5, in which on one side three circular discs of red, blue violet, and green overlap partly; the center, where all three lap, is white; the lapping colors,

termed secondaries, are yellow, peacock, and magenta; the other side shows a similar arrangement, but the discs are the secondaries; the superposition of all three at the center gives complete black, theoretically; practically, an approach that will satisfy the eye. The colors on the screen are not exact, owing to the admixture of yellow light emanating from the arc light operating the lantern. The lapping of any two of the secondary color discs of Fig. 5 gives back as a combination result the original primaries, red, green, and blue violet.

It is my privilege to have induced Mr. Ives to construct a colorimeter for use with the projection lantern, capable of showing on the screen the combination and matching of colors, as well as the resolution of any combination color into its primaries, not only quantitatively, but also qualitatively; this is the first time that this has been accomplished, and I am particularly pleased that, in connection with my introductory address as your President, Mr. Ives allows me to present this to the scientific world through this Club.

Of the two white fields side by side on the screen, one is due to the arc-light directly, and the other due to light from the same arc passed through transparencies of the three primary colors; the width of the color slits has been regulated so that the proper quantity of each color passes to combine into and match the direct white. Placing now various simple and complex colors in place of the direct white field, you will note that, by suitably varying the width of the three primary color slits, the two fields are made to match. Please note also the very noticeable change in tint that results from a variation of only 1 per cent. of the width of one of the slits. With a very little practice a user of this apparatus soon learns which of his three primaries he must add or subtract to match the color under examination.

While the three primary color theory is most generally accepted, there are those that assert that four primaries should be used as a basis for color analysis. So far as the colorimeter is concerned, it can deal with any number of primaries, as it is only necessary to provide as many mixing slits as there are primaries—two, three, four, or any desired number.*

It was stated that this colorimeter was devised by Mr. Ives in

* Various colors were thrown on the screen, analyzed, and matched. There were also shown, by means of this projection apparatus, the varying tints of different lights as compared with daylight, and the admixtures of colors producing these variations.

connection with his work in three-color photography. Mr. Ives was the first really successful pioneer in three-color photography, though some preliminary work has been done by Ducos Du Hauron, of France, and others. To date, the greatest advance toward really satisfactory reduction to broad practicability is again due to our distinguished fellow-townsman.

No doubt a brief recital and a few examples of the various methods now in use will interest you. The screen shows you a series of parallel lines of red, blue, and green. In the original slide these are very narrow—too narrow, in fact, to be distinguishable by any but the very sharpest of eyes. This next slide shows these lines still more plainly by microscopic projection. When a series of such lines are viewed at a sufficient distance, or the lines are of such small width as to be individually indistinguishable, they will combine to give the effect of white, provided, of course, that proper primary tints of sufficient purity and quantitatively correct have been chosen. If, in any way, say the blue-violet lines are suppressed or obscured, then the remaining red and green will combine to yellow. If such a screen be ruled on a glass plate and covered with a sensitive photographic emulsion and that exposed to the light from a colored object falling through the screen, then the local darkening on development will prevent transmitted light from reaching the eye, and so cut out more or less of the primary color lines, giving the effect of a transparency in natural colors. This method is due to a number of workers, as Du Hauron, Joly, Mc Donough, and others. Later workers along this line have replaced the ruled lines with stipples or dots of primary colors. Such a screen, due to Lumière, consists of more or less irregular agglomerations of red, blue, and green dots. Each dot is a dyed starch-grain particle, potato starch having been selected because of the minuteness of the grains. A much more regular arrangement, though of much larger dots, is the "Thames" screen. Still another, made up of alternating green and blue lines, crossed at an angle of about 30 degrees by red lines, is the German "Krayn" screen, made by pasting alternate blue and green thin celluloid sheets together, and cutting a veneer from the edge of the resulting block. The red lines are later printed on the veneer.

By comparing the light falling through these various screens with the light falling through three thicknesses of clear celluloid it is apparent that the various screens all absorb relatively large amounts of light—some more than others. As the light reflected from an

object to be photographed must pass the screen before it reaches the sensitive film, it is clear why color photography is relatively slow; it requires exposure about twenty times as long as direct monochrome work with the same films.*

This general method of color photography by line and stipple is capable of very good results in the hands of those highly skilled. But the plates are expensive and delicate, and the many manipulations are wearisome and difficult to carry out. Then they give only a single original, which cannot be satisfactorily manifolded. Moreover, that original is a transparency. Furthermore, if the light falling through it is necessarily different from that by which it was taken, the color effects are falsified. These transparencies should always be viewed by diffused daylight, or by light reflected from a white background. Used in the lantern, the magnification shows up the disturbing line or stipple screen. Owing to their relative density, much more powerful lanterns are necessary for line or stipple color slides than for ordinary lantern slides.

Mr. Ives approached the subject from another angle. He boldly decided on superposing three transparencies, one representing all the various gradations of red of the object, another of the green, and the third of the blue violet. Superposed in register, it is clear that these must give a correct color composite of the object. The difficulties were many and multifarious. The colorimeter had to be devised to test out and select from the many possible dyes those giving the nearest effects to truth; then these had to be sifted further for permanency; then the varying shrinkage of the films, destroying correct registry, had to be overcome, etc. Finally, the camera itself and the plates had to be drawn into the work of improvement. In a general sense any camera would answer, particularly when stationary objects are to be photographed. There would first be made an exposure for the reds, then a second one on a second plate for the greens, and then a third on a third plate for the blue violets. But as that required three successive exposures, and since registry of the three plates would manifestly be impossible if the object moved between exposures, this method was restricted to stationary objects. Nor could three simultaneous exposures be made with three separate or combined cameras, as each necessarily viewed the

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* A number of natural color transparencies by these various line and stipple screen methods were projected on to the screen.

object from a slightly different angle. Mr. Ives devised a beautiful solution of that elegant simplicity characteristic of his work in general.

In Fig. 6 the camera body A is of the box type, with the usual lens system B. The plate-holder is carried at the back in the usual way, but carries two plates, C and D, the rear one having its film side nearest the lens, and the one in front of this having its film face to face with the rear one. A third plate, E, lies in the bottom of the camera. Light from the object passes through the lens system, and a compensating color screen, F, immediately behind the lens system. The light next strikes a clear glass, G, that is placed at an angle of forty-five degrees. The front face of this glass acts as a mirror to deflect

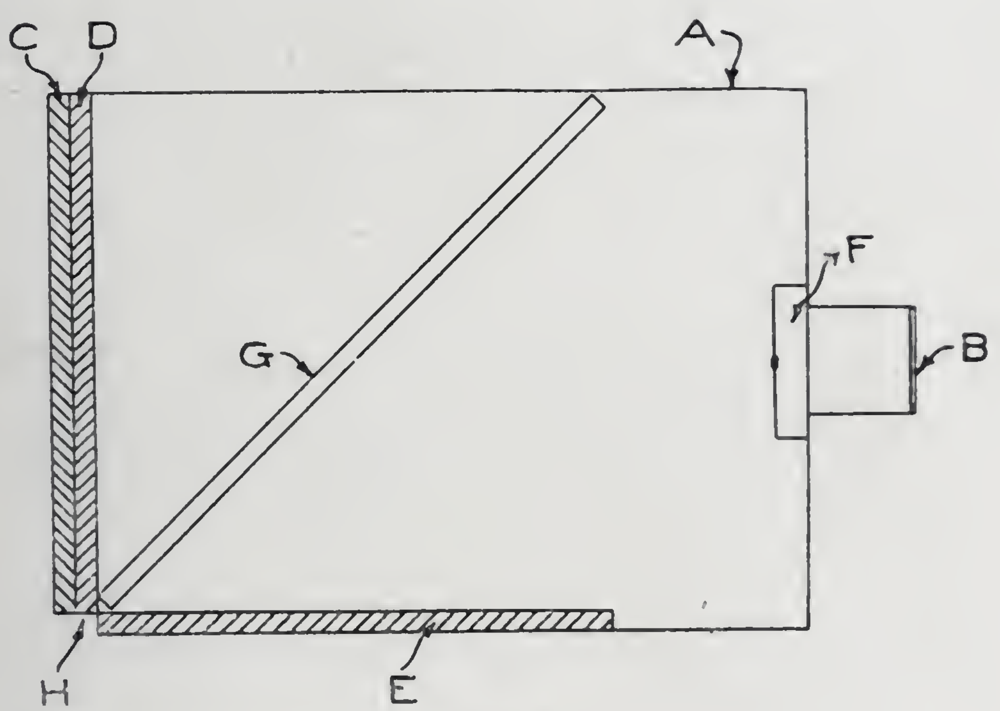

Fig. 6.

part of the light to the bottom plate, E. The remaining light passes through the glass G, through plate D, to act on the sensitive rear face of D and on the sensitive front face of plate C. It is clear that a single exposure suffices for making the three plates, C, D, and E. Each of these plates must, of course, select its particular primary color. The principle under which they do this is old, consisting of the filtering out by suitable interposed color filters. These color filters are located as follows: The compensating screen F acts also as a color filter; a second one is supplied by a varnish on the back of the inclined transparent mirror, G, and, finally, the sensitive film of D is suitably dyed to filter for plate C. Much work and patient

investigation and experimenting were necessary to secure the proper relationship of the sensitive plate emulsions, different for each of the three plates and of the color filters. Some of the difficulties may be imagined when it is realized that, even though all the light filters were of proper color and purposely balanced as to intensity of color, an emulsion slightly too fast or too slow on one plate would result in that plate being too dense or too thin, and so give not enough or too much of its color in the final result.

The arrangement of the three plates for convenient handling is also worthy of note. All three plates are attached at their lower edges, H, to a strip of gummed paper, on which they hinge like the leaves of a book. They are inserted as a unit into the plate-holder, which is slid into the camera back in the usual way. At this time the mirror, G, is held up out of the way at the top of the camera by a simple catch. When the plate-holder slide is withdrawn, that allows the first plate, E, to fall downward to its position, as shown in Fig. 6. Plates C and D cannot fall, being slightly larger than the front opening of the holder. The mirror, G, is then dropped to place, and the exposure made precisely as with any ordinary camera. This camera can, in fact, be used for ordinary work by simply leaving the mirror, G, at the top, and using ordinary single plates, roll films, or film packs. Ordinary cameras of the box type may also be readily converted for color work by adding the mirror G and slightly adapting the plate-holder slide.

The plates are developed in the usual way; the best method is by fixed time development in a standard solution, glycin preferred. A convenient arrangement is also due to Mr. Ives, consisting of a simple tank adapted to take the triple plate pack ("tripak"), with the three plates spread apart like the leaves of a book, for convenient access by the developer. Only a single developer is required, acting five to eight minutes, and the ordinary fixing in hypo and water washing. To print out, all three plates are placed side by side in a long printing-frame and the film exposed. The film is gelatin bromid, carried on a very thin celluloid backing. When the proper exposure has been made, by the aid of a very simple tint exposure meter, the film is washed out in hot water until it is clear, and then passed through a hypo. The film is now cut apart, and the three films laid each into its dye-bath of peacock-blue, magenta, and yellow respectively. In about five minutes each will have absorbed the proper amount of dye. As the absorption

power of the film and the dye-baths are all standardized for proper relationship, a more prolonged dyeing has no appreciable effect, and neither skill nor judgment as to proper dye density is needed. The dyed prints are dried in the usual way, placed in register over one another, and bound securely at the edges by passe-partout paper. For lantern slides they are also bound between clear glass plates. Obviously, any number of transparencies may be made from one set of plates. The entire process is exceedingly simple, and, owing to the thorough standardization of all the elements for themselves and in their interrelation, the results are uniform and independent of special manipulative skill or judgment.

This whole chapter of progress on the production of correct color transparencies in any quantity from a single exposure may now be said to be beyond the realm of the laboratory, and to have definitely arrived at that stage of perfection required for broad general public use. With it Mr. Ives has added to his achievements as the originator and perfector of the half-tone printing process and of the three-color printing process the further one of direct practical three-color transparency photography.

With the characteristic energy of the truly scientific inventor, Mr. Ives is already hard at work on the conquest of new worlds, and I have been privileged to see very nearly perfected color photographic prints for direct vision. I trust that it may be my privilege to have the final result brought before the world for the first time through this Club.*

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* A number of slides were shown illustrating various color phenomena, as color fringes, interferences, bands, etc.

Paper No. 1107.

PROPULSIVE MACHINERY AND OIL FUEL IN THE UNITED STATES NAVAL SERVICE.

CAPTAIN C. W. DYSON, U.S.N.
(Visitor.)

Read January 6, 1912.

Until within the last few years the improvements in propelling machinery for naval vessels, and for marine purposes in general, were few, the designers apparently considering that the reciprocating engines which they were then using were good enough, and that any further improvements in them could be made only at an undesirable increase in weight, in cost, and in complication.

This apparent view extended not only to the main propelling machinery, but also to the auxiliary machinery, with the result that each new ship was practically a copy of those that preceded it, only such modifications being made as the necessities of the particular case dictated.

With the advent of the turbine it became necessary, in case the reciprocating engine was to hold its own, to take advantage of every possible opening for improvement. Such improvements as appeared possible at the time of laying down the designs were made, and that they were desirable has been amply shown by the results on trial and in service obtained by the U.S.S. South Carolina, Michigan, and Delaware.

In the adoption of turbine machinery the Navy Department proceeded with characteristic caution, and no designs of this type of machinery were laid down until results obtained abroad were of such nature as practically to insure success.

In the fall of 1904 it was determined to lay down three scout cruisers, Birmingham, Salem, and Chester, and in order to obtain data for use in future designs it was decided to fit the Birmingham with reciprocating engines, the Salem with Curtis turbines, and the Chester with Parsons turbines.

Before these vessels were completed, in June, 1907, the Fore River Shipbuilding Company completed and tried out the Southern

Pacific Steamer Creole, which was fitted with Curtis turbines as main propelling engines. The trials were witnessed by representatives of the Navy Department, who, entirely discounting the fact that such a vessel as the Creole was unfitted by her hull and slow speed for turbine propulsion, reported on the turbines only, and after pointing out defects which could be corrected, stated that the Curtis turbine was adapted for marine propulsion.

During this same year, 1907, the designs for the battleships Delaware and North Dakota were being prepared. When the advertisement for bids for these two vessels were issued, bids were invited both for reciprocating engines and for turbines. The design of these vessels made it impossible to install satisfactory Parsons turbines, but single-unit Curtis turbines fitted in very well. Upon the opening of the bids the Bureau of Steam Engineering pointed out to the Navy Department that if turbine machinery were installed in either of these vessels, it would be at the sacrifice of cruising radius. How well based this criticism was has since been amply demonstrated by the performances of the Delaware with reciprocating engines, the North Dakota with Curtis turbines, and the Utah with Parsons turbines.

Propelling Machinery of Fast and Light Vessels.

For main propelling engines for such vessels as destroyers and torpedo-boats the steam turbine was welcomed with open arms. For such vessels, having high speed, high power, and very light foundations for the support of the propelling machinery, a very high piston speed was necessary, with the reciprocating engines which had formerly been fitted. This high piston speed, with the consequently high number of reversals in the direction of motion of the moving parts, resulted in the production of excessive vibrations of hull and machinery, and the resultant breakdowns of the engines at full power were numerous.

By the adoption of turbines, with the consequent change from reciprocating to rotary motion, the problem of engine vibration was immediately solved, and the only vibration now existing in such vessels is that due to the propellers.

The first turbine-propelled destroyers, Nos. 17 to 21, five in number, were laid down in 1906, and all the destroyers designed, built and building, since that year—a total of 29—have been fitted with turbines. Some of these vessels have the Parsons turbine, with the power distributed between three shafts, while others have the Curtis or the Zoelly, with the power distributed on two shafts.

Improvements in Reciprocating Engines.

For battleship work, in order to meet the turbines on more even ground, the principal changes made in the design of reciprocating engines are as follows:

1. Increase in ratio of L.P. to H.P. cylinder volumes from about 7 to 1 to about 10 to 1.
2. Lengthening the main steam valves in order to give short and straight steam and exhaust ports, with consequent reduction in clearances and in steam frictional losses.
3. Increase in vacuum carried in main condensers.
4. Use of superheated steam.
5. Slight decrease in bearing pressures of crank-pins and cross-heads.
6. The fitting of forced lubrication to crank-shaft, crank-pin, and cross-head journals and to eccentrics and to cross-head slides.

All these changes have not as yet been made, but 1, 2, and 4 were utilized in the engines of the South Carolina and Michigan, 1, 2, 4, 5, and 6 in the engines of the Delaware, and 1, 2, 3, 5, and 6 in the engines of battleships Nos. 36 and 37, the designs of which have just been completed by the Navy Department.

Results Obtained by the Above Changes.

Unfortunately, in the cases of the South Carolina and Michigan, no measurements of actual water consumptions of the machinery were made on the trials of these vessels. An idea of the economy realized can be obtained, however, by comparing them with their sister ships of the Connecticut class, the Delaware also being included in the tabulation:

	Minnesota.	Michigan.	Delaware.
Heating surface of boilers, sq. ft.	52,752	42,500	55,749
Superheating surface of boilers, sq. ft.	..	4,720	6,149
Total grate surface per sq. ft.	1,100	886 eq. 1,148.25 act.	1106 eq. 1439 act.
I.H.P. all machinery	20,783	19,680.6	29,529
Sq. ft. of H.S. per I.H.P.	2.538	2.159	1.888
Sq. ft. of H.S. per I.H.P. (total)	..	2.4	2.096 eq.
I.H.P. per sq. ft. grate surface	18.894	22.21 eq.	26.7 eq.
Air-pressure in inches of water	0.92	0.85 act. 1.00 eq.	2.43 1.86 act.

Let us compare the above results still further, using a series of vessels having the same type boilers as the above vessels, but all being without superheat and having the old type of naval engines.

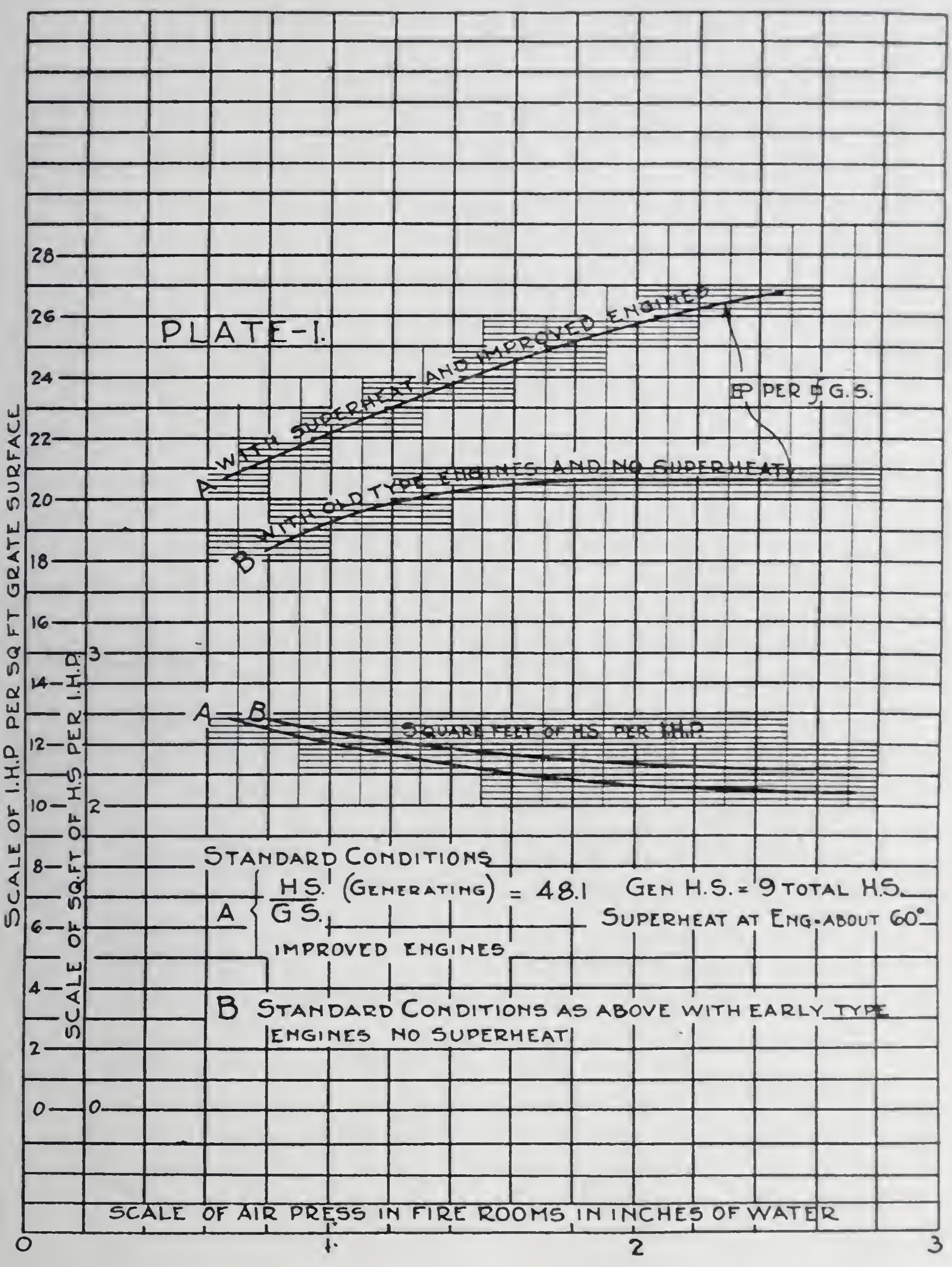


PLATE-1.
A WITH SUPERHEAT AND IMPROVED ENGINES
B WITH OLD TYPE ENGINES AND NO SUPERHEAT
IHP PER ☐' G.S.
A B
SQUARE FEET OF H.S. PER I.H.P.
SCALE OF I.H.P. PER SQ. FT GRATE SURFACE
SCALE OF SQ. FT OF H.S PER I.H.P.
STANDARD CONDITIONS
A { H.S. (GENERATING) / G.S. = 48.1 IMPROVED ENGINES
GEN H.S. = 9 TOTAL H.S.
SUPERHEAT AT ENG. ABOUT 60°
B STANDARD CONDITIONS AS ABOVE WITH EARLY TYPE ENGINES NO SUPERHEAT
SCALE OF AIR PRESS IN FIRE ROOMS IN INCHES OF WATER
0
1
2
3
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0

In the above table and in the following one the boilers are all reduced to a standard ratio of generating heating surface to grate surface of 48.1, and the air-pressures calculated as varying inversely as the ratio of the equivalent grates to the actual ones.

VESSELS WITH OLD-TYPE ENGINES AND NO SUPERHEAT.

	Minnesota.	Montana.	Mississippi.	Charleston.
Heating surface	52,752	68,000	32,648	64,000
Total grate surface	1,100	1,590 act. 1,418 eq.	768 act. 681 eq.	1,400 act. 1,343 eq.
I.H.P.all machinery	20,783	28,280	13,906	27,507
Sq. ft. of H.S. per I.H.P.	2.538	2.404	2.347	2.323
I.H.P. per sq. ft. G.S.	18,894	20.0 eq.	20.405 eq.	20.62 eq.
Air-pressure in inches of water	0.92	1.19 act. 1.33 eq.	1.3 act. 1.47 eq.	2.48 act. 2.6 eq.

Plotting the results obtained from the above tables on Plate I, we see that for an air-pressure of 2 inches of water, which is the naval limiting pressure for coal-burning Babcock and Wilcox boilers, which are fitted in all the above vessels, the use of superheat and the improved engines gives 25.6 I.H.P. per sq. ft. of grate against 20.6 I.H.P. per sq. ft. of grate with the old equipment. This is a total increase in economy of 24.3 per cent. The commonly accepted saving due to superheat is estimated at 1 per cent. for every ten degrees, which, as the average superheat used in the above vessels at full power amounted to about 60 degrees, gives a total saving due to superheat only of 6 per cent., leaving a balance of 18.3 per cent. due to the improvements in the engines themselves.

Comparison of Water Rates of Old and New Types.

The only vessels having reciprocating engines for which accurate engine water consumption measurements have been taken, up to the present date, are the scout Birmingham and the battleship Delaware. The necessary engine data for comparison are as follows:

		Birmingham.	Delaware.
Diameters	H.P. cylinder	28¼″	38½″
	I.P. cylinder	45″	57″
	2 L.P. cylinders	62″	76″
Piston-rod diameters		6″	8″
Stroke of piston		36″	48″
Revolutions at full power		191.5	128.39
Piston speed at full power		1149′ per min.	1027′.12
H.P. mean		26.4	16.17
Per cent. clearances	I.P. mean	21.34	13.57
	L.P.	21.245	12.49
Steam pressure per gage in H. P. valve chest		229.4	253

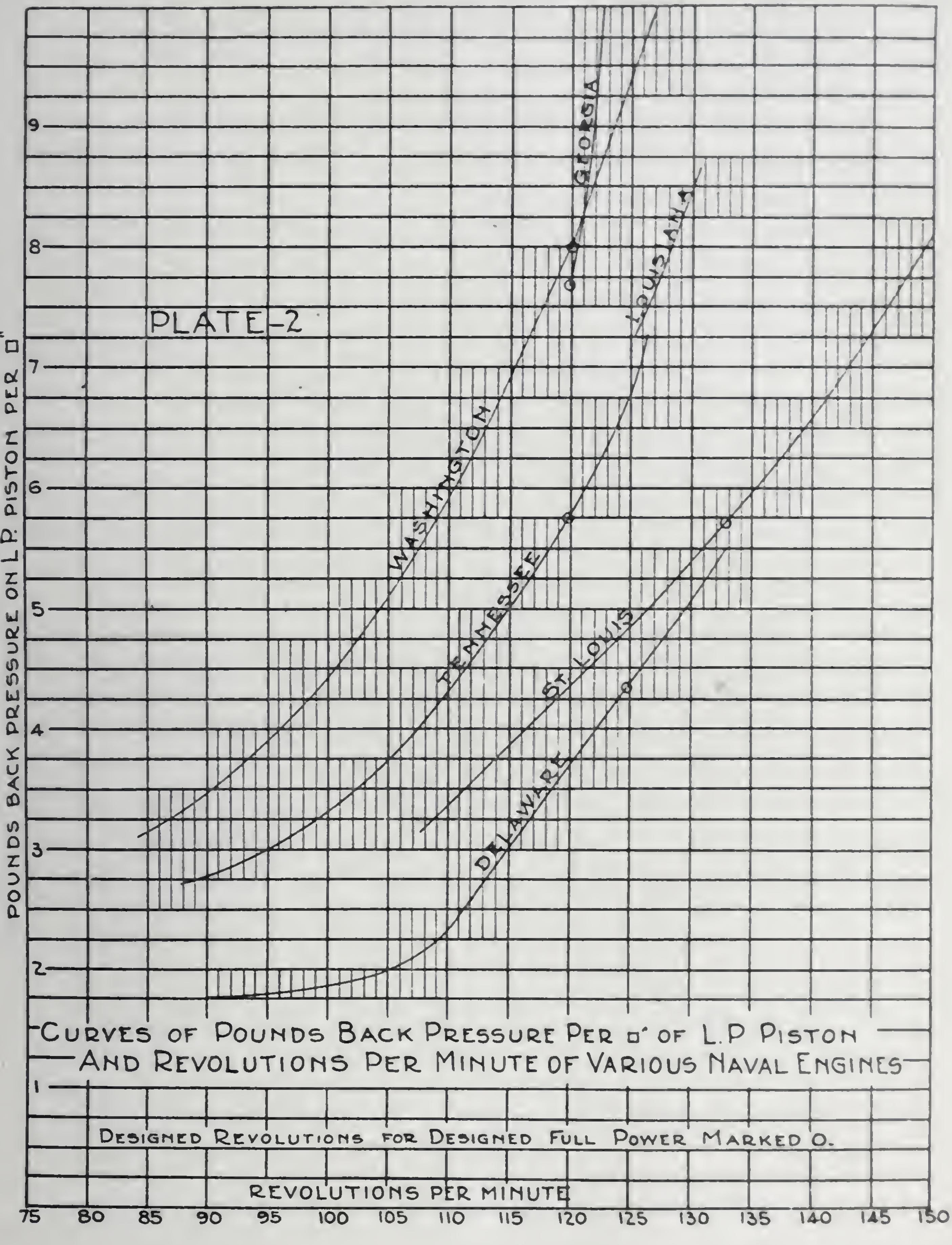


PLATE-2
POUNDS BACK PRESSURE ON L.P. PISTON PER □"
GEORGIA
LOUISIANA
WASHINGTON
TENNESSEE
ST. LOUIS
DELAWARE
CURVES OF POUNDS BACK PRESSURE PER □" OF L.P PISTON
AND REVOLUTIONS PER MINUTE OF VARIOUS NAVAL ENGINES
DESIGNED REVOLUTIONS FOR DESIGNED FULL POWER MARKED O.
REVOLUTIONS PER MINUTE
1 2 3 4 5 6 7 8 9
75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150

The Birmingham engine, of course, is handicapped at the start by its smaller size, higher piston speed, and lower steam pressure, but these handicaps cannot possibly explain away the great differences existing between the steam consumptions per I.H.P. of the two types of engines at equal fractions of power. These consumptions are as follows:

	Full Power.	⅝ Power.	⅛ Power.
Delaware	13.38 lbs.	12.7 lbs.	15.12 lbs.
Birmingham	17.30 "	15.5 "	19.00 "
Per cent. decrease for Delaware	22.66 "	18.7 "	20.40 "

The above amounts include drainage from the jackets. All leakage from stuffing boxes is unaccounted for, but if this were taken into account, the difference would be still more favorable to the Delaware, as not the slightest evidence of leakage through her valve stem or piston-rod stuffing boxes existed during the trials.

The collier Cyclops has engines built along the same lines as the modern naval reciprocating engines, and the results obtained by her bear out fully the results obtained by the Delaware. Although no superheat exists in the case of the Cyclops, the water per I.H.P., measured from her indicator cards, shows at full power less than 12 pounds, neglecting leakage and cylinder condensation.

To show the effect of the short, straight steam ports on exhaust pressures, Plate 2, showing the amount of back pressure exerted per square inch of L.P. piston area for several engines of the old type and of the Delaware, is herewith submitted.

The very low pressure shown by the Delaware is not entirely due to the ports alone, but is partially accounted for by the fact that with the Delaware's engines no live steam was admitted to the I.P. and L.P. receivers during trials, full benefit being taken of the expansion of the steam from cut-off in the H.P. cylinder to the exhaust in the L.P. cylinder.

The Delaware's engines were still further aided in the search for economy by the forced lubrication system, which, by insuring that all bearings were oil borne, quite materially decreased the friction of the load, and thus allowed the engines to turn up more rapidly than would have been the case if this system had not been installed.

The following table, giving steam and exhaust velocities, will be of interest as showing the benefit of the straight ports in reducing resistance to the flow of the steam, and thus increasing the efficiency of the engines:

TABLE OF STEAM AND EXHAUST VELOCITIES.

Ship.	Revs. per Min.	Type of Port.	H.P. Steam Veloc. Ft. per Minute (Mean).	H.P. Exh. Ft. per Minute (Mean).	I.P. Steam Ft. per Minute (Mean).	I.P. Exh. Ft. per Minute (Mean).	L.P. Steam Ft. per Minute (Mean).	L.P. Exh. per Minute (Mean).
Delaware	130	straight	6,565	5,340	6,678	6,180	10,446	7,514
Michigan	125	"	6,723	5,289	7,883	5,909	9,947	7,199
Louisiana	120	crooked	5,670	5,480	8,262	6,670	10,833	7,450
Birmingham	200	"	6,518	5,251	8,385	6,804	11,591	8,347

	Delaware.	Michigan.	Louisiana.	Birmingham.
Velocity through exhaust pipe to condenser	6,637	6,612	7,390	7,061
Velocity through main steam-pipe	8,275	8,463	8,380	7,078

All the above velocities are based on relative areas of ports and pistons and volumetric displacements per minute of the pistons. It should be further stated that the Birmingham never made 200 revolutions, but reached about 190 on trial.

Turbine Machinery for Battleships.

In the choice of type of turbine machinery for battleship propulsion the Navy Department has, up to the present time, placed turbines of the Parsons type and of the Curtis type upon an equal footing where weights and space allowed for the installation would accommodate either. In some cases the engine-room space may be very much restricted; when this is the condition, turbines of the Curtis type have a decided advantage over the Parsons, as the former type, with either one or two units per shaft, the total power being divided between two shafts, can be installed in much smaller floor area than the Parsons type, with its cruising turbines and high-pressure backing turbines, in addition to the main turbines, with the power distributed among four shafts.

An instance of this occurred in the case of the North Dakota. In this vessel the engine-rooms are only 44 feet in length. This length accommodated reciprocating engines, as in the Delaware, or a nine-stage single-unit Curtis turbine, although this resulted in a very crowded arrangement, but made the installation of Parsons turbines an impossibility if the cruising turbines were to be retained.

The Florida and Utah are both equipped with Parsons turbines

of a designed shaft horsepower of 28,000, divided among four shafts. The engine-room space required to accommodate this amount of power, together with the necessary cruising and backing turbines, is 51 feet wide by 60 feet long, while on the Wyoming and the Arkansas, with the same designed shaft horsepower as the Utah, the space has been reduced slightly to 48 feet 6 inches wide by 60 feet. In all four of these vessels the engine-rooms are much crowded, large as they are. When they are compared with the engine-room space of the reciprocating engine ship Delaware, which is 50 feet 6 inches wide by 44 feet long, we see that, with about the same width of engine-room, the reciprocating engine ship, in order to develop the same I.H.P. as shaft horsepower of the turbine vessels, requires 16 feet less in length. The importance of this saving in length is easily seen when we consider the additional displacement and armor, with consequent large increase in cost of hull, entailed when the vessel is designed for turbine propulsion.

Comparison of Engine-room Weights of Turbine and Reciprocating Engines.

At the time of writing this article the Bureau of Steam Engineering has available the completed weight sheets of only two comparable vessels, namely, the Delaware and the North Dakota.

The engine-room weights of the former vessel are 773 tons, while those of the latter amount to 783 tons. Practically no saving in engine-room weights can be looked for if turbine machinery is adopted in place of reciprocating engines for battleship propulsion.

Comparison of Efficiencies of Propulsion and Resultant Comparative Boiler Installations Required with the Two Types of Machinery.

In comparing efficiencies of propulsion the first point to be taken into consideration is the relative propeller propulsive coefficients which can be obtained with the different types of machinery used. As all three of the Dreadnaught battleships which have been tried, the Delaware, North Dakota, and Utah, had excellent to very good propellers, for the utilization of the high power, we will compare their individual propulsive coefficients with each other, taking their performances at 21 knots as a basis.

As all engineers understand, the term "propulsive coefficient" as usually applied means the ratio between the tow-rope horsepower

(E.H.P.) of the ship when fitted with all appendages and the I.H.P. in the case of reciprocating engines, or S.H.P. in the case of turbines. The Bureau of Steam Engineering assumes a mechanical efficiency of 92 per cent. for its large reciprocating engines, so that the true comparison of propulsive coefficient would be represented by the following formulas:

$$\text{Reciprocating propulsive coefficient} = \frac{\text{E. H. P.}}{\text{I. H. P.}}$$

$$\text{Turbine propulsive coefficient} = \frac{\text{E. H. P.} \times .92}{\text{S. H. P.}}$$

Using these two formulas, the propulsive coefficients of the three vessels at 21 knots were—

Delaware	122½ revolutions,	65 per cent. prop. coef.
North Dakota	265 "	53.82 per cent. prop. coef.
Utah	313 "	56.12 " " "

While the powers required for this speed were—

Delaware	23,400 I.H.P.	
North Dakota	26,500 S.H.P.	= 28,800 I.H.P.
Utah	26,400 S.H.P.	= 28,700 I.H.P.

For boiler comparisons, it is considered preferable to reduce conditions to one common condition of feed temperature and boiler pressure, and to compare the heat units absorbed by the boilers of each vessel in overcoming equal resistances of hulls. By doing this we find that at 12 knots' speed the Delaware's boilers absorbed 119,500 B.T.U.'s against 142,700 B.T.U.'s for the Utah, or that it costs approximately 19.4 per cent. more to cruise at 12 knots with the turbine ship than with the reciprocating one. At full power of 21.56 knots, the costs in heat units for the two vessels are approximately the same, namely, about 385,000 B.T.U.'s.

The above heat costs include all the engineers and the ship's auxiliaries. The North Dakota is not brought into this comparison, as in the measurements of water consumption on that vessel only the engineer's auxiliaries were included.

This equality of heat cost at full power existing for battleships of 21 knots' speed, it is not readily seen how a saving of 15 per cent. in boiler weights, as has been claimed, can be made by the adoption of turbines for main propelling machinery in such cases.

Cruising Economy.

As pointed out above, the Utah at 12 knots required the absorption of 19.4 per cent. more heat units by her boilers than did the

Delaware. Referring to equal speeds, and comparing the Utah's performance with those of the Delaware and the North Dakota, we obtain as propulsive coefficients the results given below:

Ship.	Speed.	S.H.P.	I.H.P.	Revs.	Per Cent.
Delaware	12	....	3,800	66½	69.20
North Dakota	12	3,750	4,076	140¾	61.32
Utah	12	3,800	4,130	172	53.18

The above results are all based upon acceptance trial results, and would be considerably modified in actual service, as was shown by the performances of the Delaware and North Dakota when cruising in company with the fleet.

The reciprocating engine ship in bad weather showed up as fully 20 per cent. better than the turbine ship, and in good weather at a slightly higher speed as nearly 44 per cent. better. These results were obtained on the cruise of the fleet to England and back home. In justice to the turbine it must be stated that the turbines of the North Dakota, when examined shortly after, were found to be in damaged condition, due to erosion and corrosion, although the vessel was a new ship just starting a cruise.

Points of Superiority Claimed for Turbine Machinery Over Reciprocating Machinery for Battleship Propulsion.

These are: 1. Capable of being driven for long periods of time at high powers without the liability to derangement which exists with reciprocating engines.

2. Less work required to keep them in condition, and therefore decreased engine-room force.

3. Less vibration and, therefore, resultant better gun pointing.

4. Decreased boiler power necessary to develop power required for full speed.

5. Less total floor space necessary for engines and boilers.

6. Greater economy in oil and fuel at full power.

7. Greater economy in oil at cruising speeds.

8. Greater cleanliness of engine-rooms.

9. Greater capacity for overload.

10. Greater ease of repair.

11. Maintenance of original economy due to no increase of steam leakages from wear.

Let us take these claims, item by item, and see whether they are justified by actual experience.

1. There is no doubt about the ability of the turbine to stand up for long periods of time when driven at full power, but cannot the reciprocating engine, when properly designed, do the same thing? Experience with the Delaware would seem to demonstrate that it can.

Immediately upon the return of this vessel from Chili, and just before she arrived at Boston, she received a wireless message from the Navy Department directing that she proceed to sea as soon as possible after coaling ship and carry out speed trials as follows:

Four hours at the maximum speed possible, to be immediately followed, without any interval for overhaul, by a twenty-hour run at the highest speed that could be maintained for that length of time.

In carrying out these orders the Delaware proceeded to Boston and began coaling as soon as possible. At the end of about twenty hours, during which time not a bearing nor a cylinder was opened for adjustment or inspection, she proceeded to sea, and as soon as well clear of the land began the trials.

During the first four hours the average speed maintained was 21.86 knots per hour, while for the entire twenty-four hours the average speed was about 21.3 knots per hour, the decreased speed for the twenty-four hours over that for the first four-hour period being due to fires and boilers becoming dirty and the fire-room personnel fatigued, thus automatically slowing down the ship and easing up the work on the engines as the time became more extended. It is unnecessary to point out that this same automatic easing up would have occurred with any type of steam-driven machinery where coal was used as the fuel.

Upon the completion of the trial the commanding officer of the vessel reported to the department practically as follows: "Four hours and twenty hours speed trials completed. Not the slightest disarrangement of machinery, either main engines or auxiliaries. Ship ready for immediate duty."

2, 10. These claims may be discussed as follows:

The turbine, by its very nature, is less liable to slight derangements than the reciprocating engine, but when derangements do occur, they are usually very serious, and require the vessel to proceed to a dock-yard for repair, where, as the troubles are usually blading ones, the time for repair stretches into weeks, thus losing the services of an important unit from the fighting-line for the entire time of repair. With the reciprocating engine, however, such repairs as are usually

called for are within the capacity of the ship's force, and the ship can remain on her station while the repairs are being made; in other words, turbine sickness usually requires hospital treatment, while the reciprocating engine can be cured by home treatment. Furthermore, there is as much difference between the two types when they are out of order as there is between an animal and a human being. Both give indications of being under the weather, but the reciprocating engine tells you where the trouble exists, while with the turbine you know that something is wrong inside, but what is wrong is known only after the hospital surgeons get to work.

As to the decreased engine-room force, our turbine battleships carry and need just as large a force as do the reciprocating ships of the same class.

3. As to vibration, where the reciprocating engine is well balanced and is mounted on a heavy, substantial hull, such as that of a battleship, the vibration is barely noticeable, and in the case of the Delaware and North Dakota, there appeared to be fully as much vibration caused by the propellers with the turbine vessel as there existed with the Delaware. Furthermore, if gun pointing be taken as a means of vibration, it is pointed out that the Delaware has just won the battle-practice trophy, beating out her turbine-propelled sister quite badly.

4. As for claim 4, it has been shown that with turbines for the designed full speed of the vessel a considerable increase in power over that required with reciprocating engines is made necessary by the decreased propulsive efficiency of the propellers. When turbine propulsion first became an accomplished fact, in all reports of trials great stress was laid upon the fact that the water consumption per hour per S.H.P. of the turbines was very considerably less than that per I.H.P. with reciprocating engines, but the great difference between the propulsive efficiencies of the propellers was not mentioned, this great inferiority of the turbine propeller for battleship work practically requiring the same amount of boiler power to be fitted for turbines as for reciprocating engines.

5. This claim is not justified, as Curtis turbine installations require approximately the same space, and Parsons turbines with cruising turbines more floor space, than is required for a reciprocating engine installation for the same speed of vessel.

6, 7, 8. Claim 6 is correct so far as lubricating oil is concerned, for with forced lubrication of reciprocating engine and with an open-

top oil casing, oil is thrown on the lower cylinder heads, where it vaporizes and is lost. The saving of fuel claim does not exist. Claim 8 is correct, but only at high powers. To offset these claims the working platforms of reciprocating engine installations are much more habitable on account of lower temperature.

9. This claim is justified only by the fact that turbines are not designed so close to the power requirements as are reciprocating engines. The steam areas through the blading are much larger than are necessary for the passage of the steam required for the designed power at the designed pressure. This criticism applies more particularly to turbines of the Parsons type.

11. This claim is a fact so far as the claim for no increase in leakage of steam is considered, but it can hardly be called an advantage over the reciprocating engine, as with proper care and experience the valves and pistons of the latter machine can be kept as tight throughout their service as they are the day they are put in commission. To offset this turbine claim we have the following troubles to encounter: excessive corrosion of rotors, which destroys balance, unequal expansion of rotors and of rotors and casing, which destroys clearance and results in destruction of blading, clearance troubles due to wearing of turbine and thrust-bearings, and the necessity of micrometer adjustments of these bearings to maintain clearance.

Vessels of High Power and Speed, Such as Battleship Cruisers, Scouts, and Destroyers.

When powering such vessels as the above, the power required for the high speeds becomes very great, and in order to confine ourselves to units of light weight, it is necessary to divide the power between two, three, or four shafts. Should reciprocating engines be used, they would be designed for a high number of revolutions and high piston speeds, and would thus become much more liable to derangement than are the comparatively slow-running, massive engines of the ordinary Dreadnaught battleship. In such cases we turn to the turbine as the rational power-producer, and up to date for such purposes the turbine is the machine par excellence.

In our service the battleship cruiser does not yet exist, our extra-fast vessels at present consisting of 3 scouts and 34 destroyers built and building.

As already stated, one of the scouts is fitted with reciprocating engines. She has done very good service, and below 21 knots has

been considerably more economical than her sister ships. Above that speed the turbine ships have the advantage, the percentage advantage increasing as the speed increases above 21 knots. As with these types of vessels high speed is the prime requisite, and economy at cruising speeds, while desirable, but still only a secondary consideration, no hesitation is met with in discarding the reciprocating engine as the primary propelling machine and taking up the turbine in its place.

With the Parsons turbine in these fast vessels the power is usually divided between three or four shafts, additional turbines for cruising at low and moderate speeds being fitted. These cruising turbines have been the cause of the major part of our troubles with the Parsons type; probably 90 per cent. of the blade strippings which have occurred have happened in these turbines, and have usually taken place when the injured rotor was running idly in a vacuum. In the latest destroyers, in order further to increase the cruising economy and to escape the blade troubles of the cruising turbines, these last-named turbines have been omitted, and small, rapid-running reciprocating engines installed in place of them. These engines are designed for about 350 revolutions, and are fitted with forced lubrication, the working parts being inclosed in an oil casing. They remain in operation, exhausting through the H.P. turbine until the speed reaches about 16 knots. Above this speed they will be disconnected, and the main turbines only will be used, the H.P. turbine being fitted with a couple of cruising stages for use in producing speeds from 16 to about 25 knots.

This cruising reciprocating engine has been also fitted, one engine on each shaft, to two shaft arrangements, where the Curtis or the Zoelly turbines are used as main propelling engines. With such an arrangement, however, the cruising engines are an additional weight over the already quite heavy weights of these impulse turbine units, and the advantages gained will have to be considerable to justify their retention.

The main point of difference in the different designs of these combination systems is in the designed exhaust pressure from the L.P. cylinder of the reciprocating engines to the inlet nozzle of the turbine, and the stage of the turbine at which this exhaust steam is admitted. It may be accepted as an axiom that "the higher the exhaust pressure from the engine to the turbine, the greater will be the range of speeds through which the combination will hold its superiority over the straight reciprocating or the straight turbine drive."

In the Fore River design this exhaust pressure is taken at about five pounds absolute, and is admitted into the fifth stage of the turbine, while in the Bureau designs the exhaust pressure from the reciprocating engine is taken at about 25 pounds absolute, and is admitted into the second main stage of the main H.P. turbine. With a low-exhaust pressure from the engine to the turbine at full power of the reciprocating engine the value of the turbine falls off very rapidly as the power of the reciprocating engine is reduced, and within a very short range of power the lower stages of the turbine will commence to do negative work, and thus produce a brake effect on the system, resulting in actual loss.

The Choice Between Two- and Three-shaft Arrangements for Destroyers.

The Navy Department, until the giving out of the contracts for the last destroyers designed, had made no distinction in favor of one arrangement over the other, but had laid down in the contract plans of the machinery that arrangement and type of turbine for which the greatest floor area of engine-room was required. This was the Parsons type with three shafts. In inviting bids, however, bids were asked for on contractors' plans, in addition to those on the department's plans, and bidders were always given to understand that in the consideration of bids one set of plans would receive as much consideration as the other.

The two-shaft arrangement does have the following advantages over the three-shaft arrangement, namely: Better manœuvering qualities at low speeds, better backing power, fewer propelling units, and possibly a better propulsive efficiency of propellers. This latter point is not definitely settled, however, but the writer is of the opinion that, with properly designed propellers, this superiority of the two-shaft arrangement must exist, at the low speeds in particular.

When the last eight vessels were contracted for, the department seized the opportunity offered it by the various bids to obtain the above advantages, and out of the eight, six boats of the two-shaft arrangement were taken, the remaining two being the three-shaft Parsons turbine arrangement, as shown on the department's plans. Since closing the contract for these two, revised plans have been approved changing them to the two-shaft arrangement, but retaining the Parsons turbines.

Economy and Ruggedness of the Different Types of Turbines.

Remarks under this head can be summed up in a very few words as follows: Considerable trouble has been experienced with Parsons turbines, due to stripping of blades through loss of clearance, while, since an initial fault in the L.P. blading of the Zoelly turbines of the Warrington and Mayrant has been corrected, blading troubles with the Curtis and the Zoelly turbines are practically unknown. These latter classes, due to their greater blade clearances, do not require the accurate adjustment that is absolutely necessary with the Parsons turbine, and from this fact is reaped a decided benefit in service. As to the relative economy of propulsion of the three types, the question is involved by the use of various designs of boilers with the different types. Results appear to indicate, however, that there is little difference between them, with the balance slightly in favor of the impulse reaction type.

Leaving the subject of main propelling engines, we will now describe the most important departure from early practice that has been made in late years; this is, the adoption of oil as a fuel.

Oil Fuel System of the Navy.

In adopting oil fuel for the naval service, the first thing necessary was to decide upon that system of atomization of the fuel which was best adapted to our needs and conditions. The system to be adopted must be one which would entail no loss in fresh water and the minimum additional weight possible.

The very conditions of the problem forced the department into the search for a satisfactory method of mechanical atomization. By adopting such a method no loss of fresh water would occur and no air compressors were required. The only additional weights required with such a system were those of the necessary oil pumps, piping, and burners.

After investigating the field available, the method of mechanical atomization, as developed by the Schutte-Koerting Company, was decided upon as the most promising for a foundation on which to build, and this system was adopted.

Description of the System.

The system as developed for use in the naval service really could be classed as "Oil Fuel Burning Reduced to the Simplest Form."

It consists of oil fuel supply or booster pumps, oil fuel pressure pumps, oil piping and strainers, oil-heaters, air-cones, and oil-burners. In addition are the forced draft blowers.

Functions of the Different Parts.

Oil Fuel Supply or Booster Pumps.—Handle the oil in the storage tanks or bunkers, pumping from one tank to another, filling tanks from oilers alongside, draining tanks of settled water, aiding suctions of fuel oil service pumps on long suction lines. They may be either simplex or duplex pumps.

Oil Fuel Service Pumps.—Draw from the oil mains through strainers and discharge through strainers and through oil-heaters to oil-burners. These pumps are usually duplex, of long stroke, and are large enough to be slow running. They work at a discharge pressure not exceeding 225 pounds, this pressure being determined by the amount of oil discharged and the area of the discharge orifice in the burner nipple.

Oil Fuel Heaters.—The function of these heaters is primarily to heat the oil to such a temperature as will render it sufficiently fluid to insure efficient atomization. Secondarily, the added heat may possibly add slightly to the efficiency of combustion. The first idea in heating the oil was that it must be raised to a temperature slightly above the flash point, so that immediately upon issuing from the burner-tip the oil assumes a gaseous form and bursts into flame. This high heating of the oil has been found to be unnecessary, and is also objectionable, as it produces carbonizing in the burners and pipes. It is also dangerous, as leaks in the piping lines cannot be discovered except by moving a naked flame along the line to ignite escaping gas. The temperature we now maintain is approximately 175° F., any increase above that being of doubtful value.

Air-cones.—These are one of the most vital items in the entire oil-burning system. They are in the form of a truncated cone, and carry the burner in the axis of the cone, discharging toward the base. The air for combustion is admitted through slots, with guide-vanes around the circumference of the cone, and is given a whirling motion. The velocity and amount of air admitted may be regulated in two ways—either by a conic damper around the cone, as in the New York Shipbuilding Company installations, or by an air-register carried directly across it, as in the Peabody system installed by the Cramp Ship and Engine Building Company. Both methods give excellent results.

The problem of air admission is of the greatest importance, as if it is improperly done, smokeless combustion becomes nearly an impossibility, and the burning of oil at a high rate of combustion becomes accompanied by a series of pulsations of such magnitude as to cause the boiler casings to pant and the brick linings to break loose and fall.

Oil-burners.—These are of the simplest character, and consist of an oil-pipe with a cast piece screwed on the end and forming the tip. The opening in the tip varies from 1.5 mm. to about 2.3 mm., depending upon the maximum amount of oil to be burned. Inside of this tip casting is a whirling chamber to which the oil is admitted in such a manner as to give it a rapid whirling motion around the axis of the burner. This causes the oil issuing through the tip opening to fly off tangentially as soon as free from the burner, and produces an intimate mixture of the oil with the air entering through the cone around it.

The oil burns without noise and produces a beautiful lance-head flame, nearly white in color. The combustion, by giving a slight excess of air, can be made absolutely smokeless, but the vessels usually operate with a slight haze issuing from the smoke-pipes, as by so doing they can regulate closer to maximum efficiency conditions than if no smoke is showing.

Oil Fuel for Battleships.

The first installations fitted to battleships and, in fact, the only installations until the plans of the Nevada and Oklahoma were developed, were for boilers primarily fitted for burning coal as the regular fuel, the oil fuel being used only as an emergency aid in maintaining the required steam when it became necessary to bring coal from remote bunkers to the fire-rooms in use.

The same system of atomization as already described is fitted, the burners being located between the furnace doors of the boilers.

On account of the difficulty of maintaining the necessary triple balance between oil, coal, and air supply, the results obtained are not as satisfactory as when burning either oil or coal alone. The first installations were rendered still more unsatisfactory by the reluctance of the boiler manufacturers to so modify the designs of the furnaces and furnace fronts as to meet the demands of the new conditions.

The necessary changes have, however, gradually been realized, and in the Florida, Wyoming, and Arkansas we have practically identical conditions of air admission for the oil as exists in boilers

for oil burning only, while in the Texas and New York, in addition to having this same system of air admission, the furnace volumes have been very considerably increased.

In the case of the latest design, the battleships Nevada and Oklahoma, the department has made a radical departure, and, so far as fuel is concerned, boilers and method of burning the oil, the vessels have become gigantic destroyers.

By adopting oil as the only fuel for these vessels the fire-room weights have been decreased about 360 tons, the necessary fuel weight for the designed cruising radius decreased in about the proportion of 9 to 7, the fire-room force decreased fully 50 per cent., while the total length of the ship required for boilers and fire-rooms has decreased from 128 feet to 66 feet.

Evaporation with Oil Fuel.

The evaporative results obtained by the use of oil fuel with mechanical atomization are quite good, as can be seen from the following table:

Name of Vessel.	Minimum Power.		Maximum Power.		Type of Cone and Burner.
	Lbs. Oil per Sq. Ft. H.S.	Water per Lb. Oil.	Lbs. Oil per Sq. Ft. H.S.	Water per Lb. Oil.	
Trippe	.0754	12,787	.895	11.905	Normand.
Paulding	.147	10.85	.951	11.9	"
Drayton	.132	12.88	.965	10.77	"
Perkins	.153	12.03	.911	10.34	Fore River.
Sterett	.157	11.81	1.012	10.427	"
Walke	.0827	13.20	.79	12.94	"
McCall	.136	12.579	.785	12.31	Schutte-Koert.
Burrows	.134	12.865	.755	12.937	"
Ammen	.096	10.541	.848	11.989	"
Warrington	.196	10.046	.993	10.446	S.K.-Peabody.
Mayrant	.12	11.584	1.02	11.126	"
Patterson	.088	12.582	.707	14.009	"
Terry	.147	11.95	.984	11.678	Thornycroft.
Monaghan	.108	11.349	.917	11.654	"

From this table we see that the average evaporation from actual boiler conditions for low rates of combustion was 11.91 pounds at an average feed temperature of 155.6° F. and an average boiler pressure of 238 pounds per gage, no correction for the quality of the steam being made.

For high rates of combustion these figures become 11.745 pounds, 163.5°, and 257.16 pounds pressure, respectively.

Estimating that the steam will be dry at the low rates of combustion, and that at the high rates there will be about 3 per cent. of moisture, the evaporations under the two conditions reduced to "from and at 212°" become—

For low rates of combustion, 13.23 pounds.
For high " " " 12.58 "

The above results are the average under trial-trip conditions, and were obtained with "Express" type boilers, which are unquestionably inferior to some other types. It is further worthy of notice that, as the trial-trip crews became more accustomed to the management of oil fuel, the results became better.

The results obtained with the mechanical system of atomization, burning oil under a Babcock and Wilcox boiler, with the Peabody burner and air register, as reported in the "Journal of the American Society of Naval Engineers," were as follows:

Lbs. Oil per Sq. Ft. H.S.	Lbs. Water Evap. per Lb. Oil from and at 212° F.	Equiv. Lbs. Coal per Sq. Ft. G.S. per Hour.
.259	15.86	16.13
1.56	13.7	75.34

The boiler efficiency at the low rate of combustion figured out as 80.21 per cent. and at the maximum rate as 69.29 per cent.

Conclusion.

The advance of the service has not been confined solely to improvements in the main propelling engines and in the adoption of oil as a fuel, but there has been a general advance all along the line, such as in the adoption of forced lubrication to all reciprocating engines, both large and small; in the adoption of electric-driven blowers for large vessels, and of turbine-driven blowers for destroyers; in improvements in condensing apparatus, feed-heaters, pumps, evaporating and distilling apparatus; in fact, a close watch has been kept on every item of machinery, both in its design and its operation, in order that the vessels of the navy should be maintained at the highest point of efficiency, and that the dollars of the public should be spent in such a manner as would return to the public the greatest value for the money expended.

DISCUSSION.

Rear Admiral Melville.—The modest title of this contribution, "Propulsive Machinery and Oil Fuel in the U. S. Naval Service," gives no indication of the exceptional value of this literary production, whether viewed from either a scientific, naval engineering, or a military standpoint.

The article not only contains a wealth of material relating to naval engineering development, but the subject has been handled in so clear and admirable a way that it is to be hoped that this important contribution to the marine turbine question may be extended before being printed, so that the author may thus have opportunity to enlarge upon each of the several important features that have been presented in so forceful and interesting, and yet in too limited, a manner.

A simple and logical analysis of the paper shows that Captain Dyson considers that, coincident with every marked improvement in design of naval machinery, there has been corresponding development of the marine boiler. It, therefore, seems natural in any discussion of this paper to analyze separately the progress that has been made in both engine and boiler design, and then to show the probable general trend of development where experimental research work along marine engineering lines should be conducted.

Probably no stronger tribute to the progressiveness of the engineering department of the navy could be paid than has been done in this monograph. It is one of the ablest papers that has been written in late years telling of the character and extent of the work done by our naval engineers. The Engineers' Club of Philadelphia is therefore to be congratulated upon inducing Captain Dyson to give the time and study that have undoubtedly been expended in the preparation of this classic technical article upon matters of paramount importance to marine engineering designers and shipbuilders, as well as to the engineering profession at large.

Improvement in Engine Design.

It is exceedingly significant that the Bureau of Steam Engineering of the Navy Department realized, over twelve years ago, that in order to insure economy and to obtain a better balancing of engines, it would be essential to change the proportion of cylinder ratios. The improved cylinder arrangement of the cruisers Cincinnati and Raleigh, built in 1902, combined with the efficient B. & W. boilers that had been installed in those vessels, gave efficiency results that had not been previously surpassed by the naval reciprocating machinery of any nation. About this period also the attention of the engineering world began to be concentrated upon the turbine work of Sir Charles A. Parsons in England and Mr. C. G. Curtis in America. There is no doubt but that this turbine experimental work had a very direct influence in causing the designers of reciprocating engines to realize the fact that it was then incumbent upon them to overcome, wherever possible, the inherent failings of the reciprocating type, if that design of engine was to be continued in battleships for propulsive purposes. The improved marine reciprocating engines of the battleships Michigan, South Carolina, and Delaware undoubtedly reflect the work done in the effort to stem the tide against the installation of turbines in our naval vessels.

The improvement in design of reciprocating engines had, however, been neg-

lected too long to effectually stem the trend toward marine turbine development, and therefore it was in the direction of the later type of installation that the maritime world began to look for that progress and advance which were demanded by the army of trans-Atlantic tourists and by naval interests. While the demand for continuous high speed was too persistent to wait upon the progressive development of the reciprocating type, it is extremely probable that, if the same energy, research work, and financial outlay that had been expended in developing the marine turbine had been used in improving the reciprocating engine, the extent of the turbine installation now afloat would be but a fraction of what is in existence.

The research work, patience, and engineering talent devoted to the development of the marine turbine was of world-wide benefit, and the special work of Sir Charles A. Parsons undoubtedly places him in the front rank of the world's great inventors. The invention, however, of the expanding nozzle by DeLaval probably constituted the one important and distinct feature of turbine advance that contributed most to the scientific development of the art.

Limitations as Regards Turbine Installation.

As Captain Dyson states, the machinery installation par excellence for destroyers, scouts, and vessels demanding continuous high speed is that of the turbine design. The anticipated economy, even at high speed, of such vessel has not, however, been obtained. This is due in great part to the inefficient propulsive effect of the propeller when operated at the high speed that is a concomitant of the direct-driven turbine. At low speed the existing marine turbine installation is well known to be an exceptionally wasteful appliance. It is exceedingly doubtful, however, if either Parsons or Curtis ever intended their design of turbines to be installed in any other type of ships than those which were to be operated at continuously high speed. The limitation of the direct-driven turbine as regards economy was well known to naval engineers even before a single trans-Atlantic steamer was fitted with such an installation.

Incidental to this phase of the subject I might state that in 1904 I was invited by Mr. George Westinghouse to make a careful study of the marine turbine situation in Europe, and to that end I spent over four months with my late partner, Mr. John H. Macalpine, in a study of the subject. Unusual opportunities for securing reliable information as regards turbine development were given us. The thoughtful views of many leading continental authorities upon the turbine were likewise obtained. The result of this investigation was embodied in a report dated May, 1904, wherein the following conclusions were stated:

> "We have already stated that we have been led to believe it would be injudicious to apply the turbine to other than very fast ships which have to run a very small proportion of their time at cruising speed; and even in the case of fast ships the advantages have been far overstated.
>
> "If one could devise a means of reconciling, in a practical manner, the necessary high speed of revolution of the turbine with the comparatively low rate of revolution required by an efficient propeller, the problem would be solved and the turbine would practically wipe out the reciprocating engine for the propulsion of ships."

Contrary to the views of many thoughtful naval engineers, and probably in opposition to the advice of the several inventors, turbines were installed in vessels

which were not designed to be operated at continuous high speed. The installation of Curtis turbines in the yacht Revolution and in the Morgan Line Steamer Creole are examples of the keen desire that existed upon the part of individuals to discard the reciprocating design, even though the development of the turbine had not progressed to a point to warrant its installation in vessels operating under such moderate speed.

Advantages of the Turbine for Marine Purposes.

A study of Captain Dyson's paper conclusively shows that of the eleven important specific advantages claimed for the superiority of the marine direct-driven turbine machinery over the reciprocating design for battleship propulsion, only four of these claims are unreservedly admitted. The distinguishing advantage of the turbine installation is its capacity of being driven for long periods of time at high powers without the liability to derangement which exists with reciprocating engines. As regards weight, floor space, cost, and time for construction, the direct-driven turbine installation offers no perceptible advantage over the reciprocating type. Due to its inefficient propulsive efficiency, arising from the high speed at which it must be operated, the direct-driven turbine installation is particularly at a serious disadvantage as regards its manœuvering qualities. The number of tugs that are required to berth a modern ocean-liner, fitted with a turbine installation, best tells of the inefficiency of this type of engine for manœuvering purposes. By reason also of the fact that the reversing power of even the most satisfactory marine turbines has not yet equaled 60 per cent. of the go-ahead power, the manœuvering quality of turbine-driven ships is necessarily inferior to that of vessels fitted with reciprocating engines.

Thermal Inefficiency of the Existing Marine Turbine.

It is a matter of exceeding importance to note that the various steamship companies operating turbine-driven vessels are exceedingly reluctant to give any information relating to the actual steam consumption of these vessels. Substantially the only reliable data available to the public as regards the relative thermal efficiency of similar sized vessels fitted respectively with turbine and reciprocating engines is that furnished by the U. S. Navy Department. The comparative tests made with the similar sized scouts Salem, Chester, and Birmingham, together with the relative performances of the similar sized battleships Delaware and North Dakota, afford the only reliable and extensive data that is extant concerning the comparative efficiency of the reciprocating engine and turbine under various similar conditions. The work of the Bureau of Steam Engineering in collecting and tabulating this data represents some of the most valuable scientific research work and investigation that has ever been made under national auspices.

Confirmatory of the information furnished by the Navy Department as to the economic inefficiency of the direct-driven turbine installation for vessels cruising at a moderate speed, some very valuable circumstantial evidence is obtainable sustaining the Bureau of Steam Engineering's investigation of the matter. The Curtis installation on the Yacht Revolution was so inefficient that the turbines of that vessel had to be placed on the scrap-heap. In the case of the Creole

it is well known in engineering circles that the coal consumption of this vessel on a round-trip voyage between New York and New Orleans was about 50 per cent. in excess of that of the sister ships Comal and Antilles, vessels of the same tonnage and fitted with reciprocating engines. The Creole was never able to develop the speed that was secured by her sister ships. There was an effort made to ascribe the inefficiency of the Creole turbine installation to the fact that this ship was fitted with water-tube boilers; but in refutation of this statement it is only necessary to tell that with an installation of reciprocating engines replacing the turbines, the Creole, with the same boilers, was brought up to the high efficiency of her sister vessels Comal and Antilles.

It is common knowledge that in some of the trans-Atlantic steamers fitted with turbines it has been found necessary to install additional bunker facilities in order to insure a reliable coal-supply for other than a fair-weather voyage. The trans-Atlantic vessels fitted with reciprocating engines, as a rule, reach port with at least two or three days' reserve of coal in their bunkers.

The turbine-driven vessels are well known to have a much smaller reserve, and this fact affords quite conclusive testimony that the efficiency results of the marine turbine are considerably less satisfactory than were expected. This is a subject of exceeding importance to the traveling public, and it would appear as if this matter is a problem deserving of special investigation by national authorities. Should there not be some legislation whereby no trans-Atlantic steamer should be allowed to engage in passenger service unless her coal-bunker capacity was of such volume as to contain at least two days of reserve coal beyond that required for the ordinary winter passage?

Wide Divergence in Efficiency Between Land and Marine Turbines.

There is a marked, even radical, difference in the performance of turbines designed for power stations on shore as compared with the installations required for marine purposes. The shore turbines are operated at a constant speed and variable power. The marine installation must be operated at both variable power and variable speed. The shore installations are usually designed to give a high steam economy at full load with nearly an equally good steam rate at 150 per cent. of full load. For naval vessels which cruise mostly at moderate speed it has been found that the direct-driven turbine is very costly to operate when running under medium speed condition.

In the land installation of turbines there are substantially no limitations as regards height, floor space, and weight to be encountered. The designer is not compelled to take into consideration the problem of propeller efficiency. In the discussion of the marine phase of the matter the efficiency of the land installation cannot be used as a criterion. In marine work the boiler designer is also subjected to all manner of limitations, and therefore the steam supply to the marine turbine can be obtained only at greater expense than the cost of supply to the shore turbine.

The Necessity for an Efficient Installation of Reduction Gear for Marine Turbines.

Among the first American firms to acquire the right to manufacture the Parsons turbine was the Westinghouse Machine Company. The detailed plans of

Sir Charles A. Parsons were studied with exceptional care by the experts of that company. Extended investigation and experimental research work were conducted in order to note if it was possible to improve the machine, as regards either economy, efficiency, or endurance. The research work of Mr. Westinghouse as regards the development of the turbine is recognized throughout the world as experimental investigation of the highest order. It may be incidentally stated that when the Westinghouse Company secured the right to manufacture the Parsons turbine, this company was a large manufacturer of reciprocating engines, and this particular industry about that period was an exceedingly profitable one. The progressiveness of the Westinghouse Company and its receptiveness for information as regards turbine development are, therefore, attested by its early action in taking up the manufacture of such appliances.

In his turbine research work Mr. Westinghouse became impressed with the military importance of utilizing the turbine for marine purposes, and particularly for our naval needs. As he had served as an officer in the Engineer Corps of the Navy during the Civil War, it was quite natural and logical that the naval feature of the problem should appeal very strongly to him. The essential elements of propeller design were also thoroughly familiar to him, and, therefore, the problem of overcoming the loss of efficiency resulting from using a propeller of small diameter and excessive speed soon commanded his thoughtful and serious consideration.

As a sequel to Mr. Westinghouse's extended consideration of the naval phase of turbine development the firm of Melville and Macalpine was engaged as consulting engineers, with special reference to marine turbine work. It was the particular desire of Mr. Westinghouse to have this firm carefully consider the question as to whether it would be possible to secure propulsive efficiency by interposing some form of reduction gear between the turbine and the propeller shaft. The previous efforts to develop an efficient reduction gear had not resulted in any material success in securing the end desired. The Fottinger water system of reduction gear is possible only for limited applications, due to the marked loss in transmitting power in such manner. The efficiency of an electric motor drive, however, for such purpose will soon be tested in the United States collier Jupiter, and the result of this particular experiment will be watched with exceeding interest by the electric and marine engineering world.

In the transmission of the many thousands of horsepower that now comprise the motive power installation of both the modern battleship and fast ocean-liner, it was recognized that certain inherent weaknesses connected with transmission gear, and particularly as regards its application to marine installation, would have to be overcome. It was realized that even with substantially perfect cutting of the teeth of the gearing the marine reduction installation would probably possess but little endurance if it was attempted to maintain satisfactory alinement by the ordinary arrangement of line-bearings.

Special attention was, therefore, given to the problem of developing a gear arrangement in which there might be incorporated some feature whereby there could always be maintained an automatic alinement of the pinion shaft, thus substantially insuring even tooth pressure. The outcome of thoughtful study and painstaking investigation was the development of what was originally known as the Melville and Macalpine reduction gear, with its self-adjusting floating

frame to carry the pinion shaft. Mr. Westinghouse undertook the construction of this experimental gear. From the first the arrangement was quite successful. After effecting minor changes in the original design the experimental gear transmitted for long periods about 6000 horsepower, with a loss in energy of only 1.5 per cent.

Original Difficulty in Cutting the Gearing.

It may be interesting to know that when the original design was made for this reduction gear there was no machine-shop in the country that could or would guarantee the reliable cutting of gear of the size required. The gears desired were 72 inches in diameter, 22 inches face, and with a pitch of 1¼ inches. The pinions were to be 14 inches in diameter. Both gears were to have an angle on the face of 30 degrees. The distance between the centers of the gears was to be 4 feet, in order to make room for a middle bearing on the pinion shaft, so as to prevent springing of the shaft, and thus avoid consequent non-alinement of the gears.

Several bids to build a machine that would cut these gears were received from different firms. One company offered to build a tool and cut the gears for $16,000. No American firm, however, would guarantee the necessary accuracy of cutting. Finally a contract was made with Schuhardt and Schutte, of Berlin, Germany, to build a machine and cut the first set of gears required. The cost of this machine was $8,500, and the price of cutting the first set of gears was $800. The forgings were made by Krupp, of Essen, Germany.

The firm of Schuhardt and Schutte guaranteed the accuracy of the teeth to $\frac{1}{1000}$ part of an inch. I regret to say this degree of accuracy was not realized, and it took considerable time to scrape the teeth to true bearing. This was due to a considerable extent to the springing of the machine. Mr. Westinghouse's experts, however, found that, by strengthening the frame of the machine and by cutting the worm driving gear in two parts, then turning the worms on their axes and recutting new hobbing tools, all inaccuracies were eliminated. At the present time all gears are so accurately cut with this arrangement that the gears can be removed from the machines and put to immediate service.

The same may be said of all smaller gears that are being cut by the Gould machines manufactured in Newark, N. J. They are turning out perfectly true gears, but only for smaller machines, such as are used for single-phase dynamos, centrifugal pumps, and for other appliances manufactured by the Westinghouse Company.

Five years ago, therefore, there was no gear-cutting machine in the country that could cut such gears with a fair degree of accuracy, and even the imported machine fell far short of its guarantees. Happily, now, through the efforts of the engineers of the Westinghouse Machine Company, gears of the largest size can be cut, placed in the frames, and set to work without having any scraping or fitting required to the teeth.

It is but just, however, to Messrs. Schuhardt and Schutte to state that the reason of the inaccuracy of their work was due more to the springing of the machine than to its design. But it is more to the credit of Mr. Westinghouse that he undertook the work of developing this tool to make it adaptable for practically any work within the capacity of the American machine-tool maker.

Efficiency Limits of the Marine Turbine.

The practical thermal advantage of using a reduction gear is very graphically shown in Fig. 1. It will be observed that when operating the turbine between certain limits marked efficiency results. By the introduction of a reduction gear the turbine can always be operated at such speed that is most conducive to efficiency and economy.

Fig. 1 shows the general relation existing between steam consumption and revolutions of a modern turbine. It will be observed that efficiency is high and uniform between points A and B. The portion of the curve, however, that is most frequently used in marine practice is the portion shown hatched between D and E. Between the ranges that are hatched it will be noted that efficiency

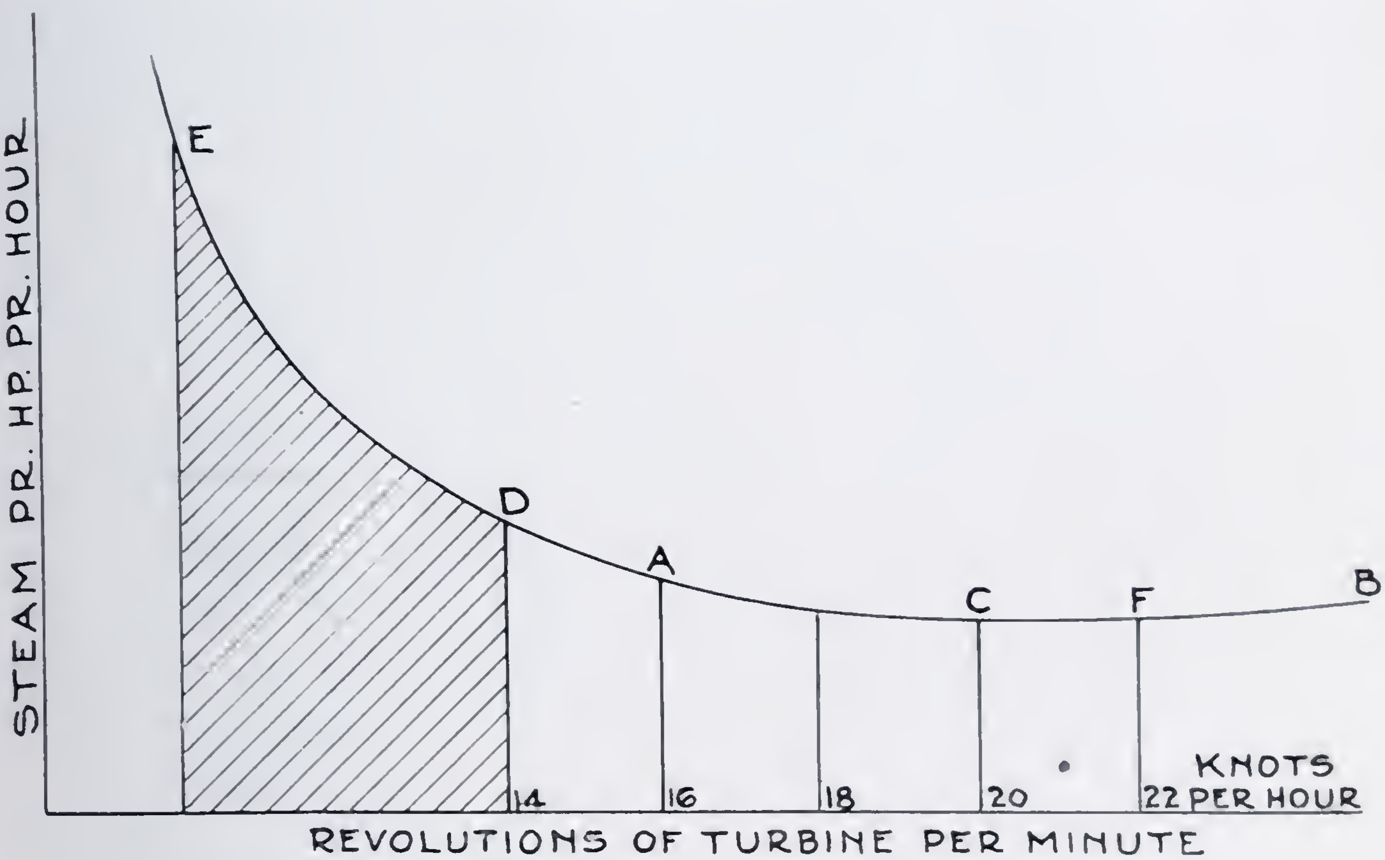


Fig. 1.

as regards water consumption is very poor. By the use of a reduction gear the turbine can always be operated within the limits included between D and B, and thus at all speeds of the turbine fitted with a reduction-gear installation a satisfactory water-rate consumption is obtainable.

Turbine Development Augmented by the Reduction Gear.

The progressiveness and patriotism of Mr. Westinghouse in developing an efficient reduction gear are worthy of the special recognition of the navy and the nation. As a result of his action in developing this appliance, every firm, directly or indirectly interested in the development or use of the marine turbine, will be compelled to give increased consideration to improving its economy, efficiency,

and endurance. The public is certain to be benefited by securing a more efficient product at a much reduced cost.

It may be incidentally stated that Mr. Westinghouse's investigation of the naval phase of the matter was not the result of impulsive action. As an ex-officer of the navy in the Civil War, Mr. Westinghouse was thoroughly familiar with the difficulties that had been encountered in operating the geared machinery installed on some of the naval vessels engaged on the blockade of the southern ports. His experience as a successful and extensive manufacturer of heavy machinery had given him an intimate knowledge of the expense and difficulty encountered in turning out accurately made gearing. His age and experience naturally constituted him an extremely conservative expert upon this subject, and his progressively growing confidence in the belief that the reduction gear was a necessity for marine purposes has commanded the thoughtful attention of the engineering world.

Under the personal direction of Mr. Westinghouse the test apparatus of the reduction gear was manufactured at Pittsburgh. Despite the fact that the usual difficulties incidental to the building of every new contrivance were encountered, the experimental gear from the first operated remarkably well.

Development of the Gear.

While the action of the floating frame gear was quite successful, the experiments carried on at Pittsburgh showed that it was extremely advisable, if not absolutely essential, to incorporate a modified arrangement for floating the pinion bearings. This improvement was the outcome of the personal work and experiment of Mr. Westinghouse, and is contained in the arrangement installed on the collier Neptune.

In this modified form the pinion shaft is carried in a two-part frame. There are three shallow cylinders and pistons, one under each lower bearing. There are also three similar cylinders and pistons for controlling the motion in the opposite direction of the upper part of the frame. Oil under pressure for floating the frames is obtained by the pumping action on the bearings. The pressure is thus automatically regulated so as to correspond exactly with the load of the work being done. The arrangement really constitutes an automatic dynamometer of the most accurate character for indicating and recording the shaft horsepower of the turbine. This may be regarded as one of the most interesting phases of this gear. There can thus be readily observed, by a reading of the dynamometer, the horsepower developed at any second of time while the machinery is in motion.

This hydraulic arrangement has thus not only accomplished in a substantially perfect manner the maintenance of uniform tooth pressure, but it has also almost eliminated vibration as well as objectionable noise. In fact, it is now practicable to install and use both pinions and main gears just as they come from the cutting machines.

Before the floating piston arrangement of reduction gear was installed on the Neptune it was observed that pitting of the pinion teeth was occurring. With the fitting of the piston arrangement, however, the pitting ceased, and the teeth of both gear and pinion are now reported to be progressively improving in appearance.

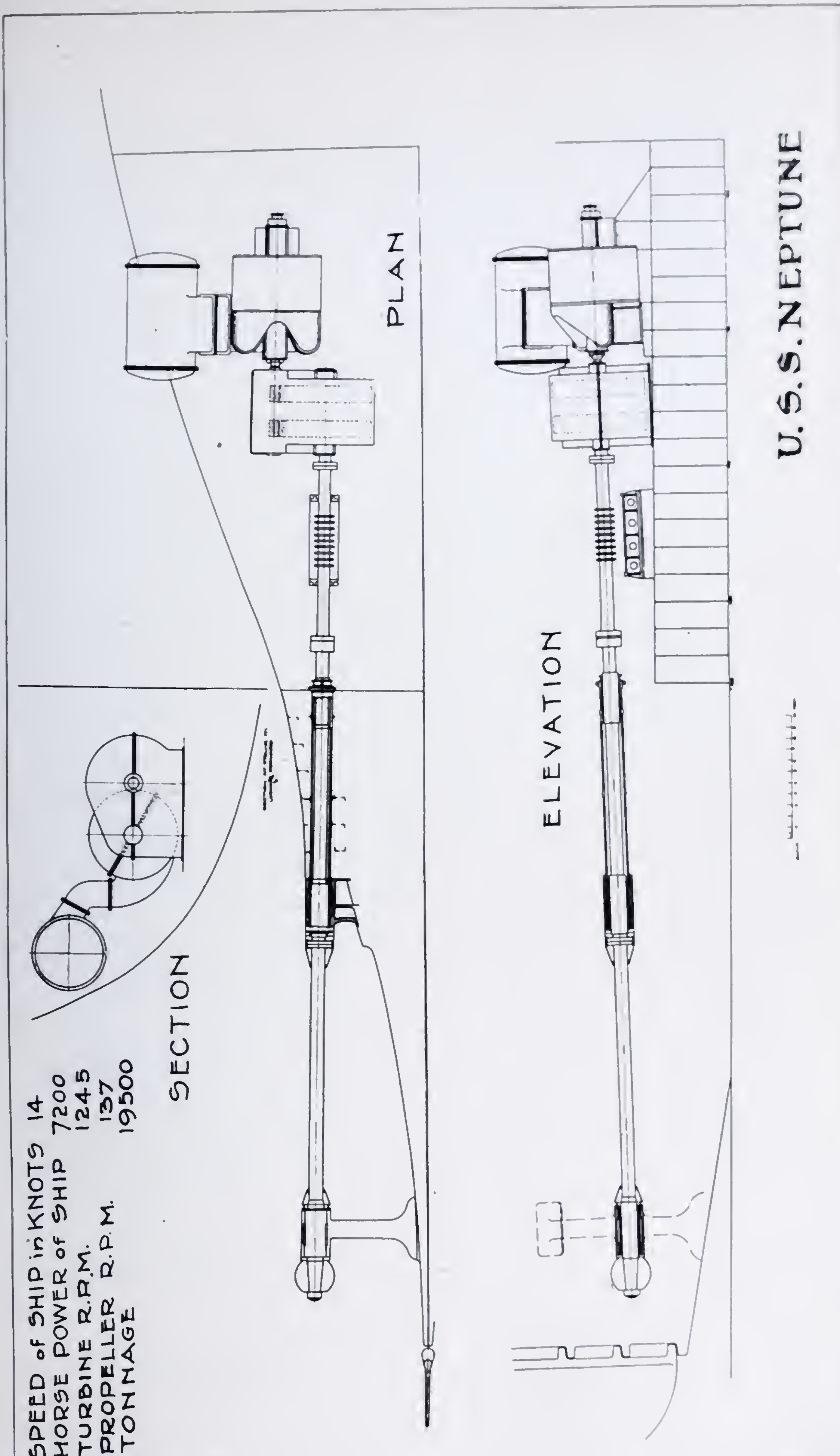

SPEED of SHIP in KNOTS 14
HORSE POWER of SHIP 7200
TURBINE R.P.M. 1245
PROPELLER R.P.M. 137
TONNAGE 19500
SECTION
PLAN
ELEVATION
U.S.S. NEPTUNE

Fig. 2.

The Trend Toward the Installation of Reduction Gear.

Before the publication of illustrations and full descriptive matter of this reduction gear, as contained in "London Engineering," it was openly stated, by Sir Charles A. Parsons and others, that reduction gears were unnecessary, and that in some cases they could not be made successfully to transmit the excessive power required.

The publication of the results of the experimental tests conducted by the Westinghouse Company undoubtedly changed the viewpoint of many of these critics. Even Mr. Parsons substantially acknowledged the value of a reduction gear, although claiming that automatic alinement of the pinion shaft was unnecessary. With a practical recognition of the trend of turbine development, therefore, Sir Charles A. Parsons subsequently had the collier Vespasian fitted with turbines and with a reduction gear in fixed bearings. The extent of this installation, however, is comparatively small. It comprises two turbines, each of about 500 H.P., the intervening reduction gear being without automatic alinement. Reduction gear of the width and capacity of that installed on the Vespasian had, however, been employed in manufacturing for years, but never without vibration and noise. It is pertinent to note that the H.P. of the Neptune is 7500 I.H.P., or about fifteen times that of the Vespasian.

The trend to the use of reduction gears is growing in Great Britain. It is stated that several British naval ships now in course of building are to be fitted with Parsons turbines and reduction gears. Several merchant vessels, it is likewise understood, will be fitted with such gears. The main shafts and pinions of these vessels, as in the case of the Vespasian, will rotate in fixed bearings. When one takes into consideration the tendency of the propeller shaft under certain contingencies to spring, the advantage of some flexible arrangement ought be apparent. The vibration and working of the hulls of ships in rough weather are also factors that show the necessity of providing some automatic alinement of the pinion shaft by means of some reliable method like the piston arrangement of Mr. Westinghouse.

The Reduction Gear Installation on the Collier Neptune.

The Neptune is a fleet collier, carrying 2000 tons of bunker and 10,500 tons of cargo coal. The propelling machinery was intended to be of two three-cylinder, triple-expansion engines of vertical marine type. The engines were designed to make about 7200 collective I.H.P., with a working steam pressure of 190 pounds above the atmosphere. Her designed speed, when carrying a full cargo, was 14 knots.

At the request of the builders the Navy Department permitted the substitution of a twin-screw installation of turbines and reduction gear for the original reciprocating arrangement of this collier. It was, however, only after the experimental reduction gear had been tested to the satisfaction of representatives of the Navy Department that the conditional change was permitted.

Instead of the original Melville and Macalpine floating frame arrangement, the modified piston arrangement of Mr. Westinghouse was used.

The turbines of the Neptune have the following important and distinct fea-

tures: It should be stated that the Neptune is substantially a sister ship to the Cyclops.

(*a*) The total weight of the main engines, reversing engines, and turning gear of the Cyclops is about 575,000 pounds. The total weight of the turbines and reduction gear of the Neptune is about 235,000 pounds. The weight of the propelling machinery of the Neptune is, therefore, only about 40 per cent. of that of the Cyclops.

(*b*) There is but a single casing and rotor attached to each propeller shaft of the Neptune. This turbine is used for both ahead and backing purposes. The design of the gear has been so arranged that it requires only twelve seconds to reverse from full-ahead to full astern.

(*c*) Each casing has been so designed that the upper half is hinged to the lower half, thereby enabling the upper half to be swung back for a quick inspection of all blading. All main steam and exhaust connections are made to the lower half of the casing.

(*d*) Any or all of the blading can be renewed, if necessary, without unseating the rotor.

(*e*) A flexible packing prevents leakage between the ahead and reverse portions. No longitudinal adjustment of the rotor is required.

(*f*) A new form of thrust bearings, capable of supporting heavy end-thrusts, keeps the rotor in its exact position.

(*g*) Valve mechanism, hydraulically operated, regulates the direction of motion and speed of the turbines by opening and closing a greater or lesser number of primary nozzles.

(*h*) The direction of speed, as well as the power being exerted by each turbine, is indicated by pressure gages. Self-recording gages make a continuous record or log.

(*i*) The installation of the machinery of the Neptune was likewise intended to afford a practical demonstration of the utility and military value of an efficient system of bridge control in operating the propelling engines from the bridge or pilot-house of the vessel. It was Mr. Westinghouse's belief that the railroad problem of distant signaling and air-brake control was a more difficult one than that of the control from the bridge of a war-vessel or ocean-liner. It was, of course, understood that some minor difficulty would be encountered, and certain changes would have to be effected in bringing about the result, but that the ultimate satisfactory solution of the problem was neither a difficult nor a protracted one.

There was, therefore, incorporated a control apparatus whereby the engines could not only be operated from the platform in the engine-room, but could be equally well operated from the bridge; that is to say, that the turbines could be operated at any speed in either direction from the bridge more readily than signals could be transmitted to the engine-room. This control mechanism has performed its intended functions most creditably, and has thus opened a new field in marine engineering of high value to those directing the movements of a single vessel or of a fleet.

(*j*) The turbines of the Neptune have impulse wheels acted upon by jets of steam under boiler pressure discharging into a chamber from which it passes through what is now technically known as Parsons blading. To obtain the highest efficiency in the impulse part requires the use of a series of nozles subject to boiler

pressure, a greater or less number to be opened according to the speed of the vessel to be attained. This arrangement of nozles and impulse wheels affords the very best kind of pressure-reducing apparatus.

(*k*) The manœuvering qualities of the geared turbines were found to be exceedingly satisfactory. As the weight of the rotor of the Neptune was approximately about 8 tons, while that of the North Dakota was over 80 tons, it can be appreciated how easily, prompt, and reliable reversal of the Neptune's rotors could be effected.

(*l*) The reduction gear worked without distinguishable rumble, and this was evidenced by the fact that the vibration of a 30 kilowatt dynamo, installed in the engine-room, drowned the noise of the reduction gear, as well as that of the main turbine. The whistling of the steam through the nozzles of the turbine, and the vibration of the illuminating set, are substantially the only noticeable sounds heard in the engine-room of this collier.

Official Trial of the Neptune.

The official trial of the Neptune occurred in July, 1911, and the operation of the reduction gear was both satisfactory and efficient. While the efficiency performances of the vessel were not up to contract requirements, the reduction gear was in no manner responsible for such deficiency. Since the official trial the following information has been obtained as regards the conditions prevailing in the engine- and fire-rooms during that test:

(*m*) The efficiency of the propellers was but 54 per cent. The efficiency of the Cyclops propellers was 72 per cent. Since the trial more efficient propellers have been fitted on the Neptune.

(*n*) The steam valves to the steering engine, anchor engine, as well as to 24 winches, were open during the entire trial. The resulting loss of fresh water was chargeable to the turbines.

(*o*) Fresh water for bathing purposes for the crew, officers, and passengers was charged against the turbines, after a small tank of fresh water intended for this purpose was pumped out.

(*p*) The required sea speed was obtained during the first hour of the test. The stoking after the first hour was exceedingly inefficient, it having been reported that as many as 20 shovelfuls of coal were thrown into a single furnace at one firing.

(*q*) The main circulating pumps are too small for the work required of them. The arranging of piping between the main injection valve, the main condensers, and the outboard delivery valve is exceptionally inefficient. There were sharp and unnecessary bends in the piping between the main injection valves and the centrifugal pump; between the circulating pump and the condenser; and between the condenser and the outboard delivery valve. It is only necessary to state that the entering circulating water was delivered at the top of the condenser and discharged from the bottom to tell how inapplicable the piping arrangement was for a turbine installation of marine machinery.

The Water Consumption Guarantees of the Neptune.

The confidence of Mr. Westinghouse in the efficiency of the Neptune's machinery installation was so great that the steam consumption guarantees for the

forty-eight hours' speed trial were those corresponding to the accomplishments of a very efficient reciprocating engine. If the steam consumption guarantees of the Neptune had approximated the requirements of turbines for battleships, the guarantees would have been greatly exceeded.

On the cruise of the North Atlantic Fleet to Great Britain and return in the winter of 1911 the cruising efficiency of the Delaware in good weather was 44 per cent. better than that of her sister ship, the North Dakota, which was fitted with turbines. It would, therefore, seem but equitable and just that in comparing the efficiency results of a primary installation of reduction gear the comparison should have been made with an ordinary turbine installation, since the design and purpose of the reduction gear were to supplant the direct-driven turbine and not the reciprocating type of engine.

The marked improvement of the second marine turbine engine, built by Sir Charles A. Parsons, over the first engine of such design, ought to be representative of the distinct advance that can be expected in the performance of the machinery of the Neptune when the inherent defects existing in the auxiliary machinery installation of that vessel are made good. It is particularly important to note that every inherent defect in the auxiliary machinery installation and management of the boilers had no relation whatever to either the design or operation of the reduction gear.

The Operation of the Reduction Gear under Rough Weather Conditions.

Since this paper was read, the Neptune made a winter voyage with a full cargo of coal from Boston to Guantanamo, Cuba. During this voyage the ship encountered two days of exceedingly heavy weather, during which the vessel pitched to such an extent as would have caused an ordinary reciprocating installation to have raced considerably. Reports from the ship state that the effect of heavy pitching was not noticeable upon the reduction gear.

It was considered by many marine engineering experts that when the Neptune encountered very heavy weather there would be serious liability of impairment to the reduction gear as a result of the propellers being subjected to excessive shock. Upon reaching Guantanamo a most careful and critical examination of both the pinion and the gearing was made. There was no perceptible evidence that the severe strain to which the gear had been subjected for two continuous days had affected the condition of the teeth of either pinion or gearing in any manner whatever.

Even during the two days of heavy weather there was no slowing down of the engines, since the marked absence of vibration gave evidence that the reduction gear was so designed as to gradually and efficiently take up all the shock and strain to which it had been unduly subjected from the pitching of the vessel.

The Military Possibilities of the Turbine Reduction Gear.

In the race for naval supremacy every naval engineering designer has striven to obtain four distinct advantages that appear particularly well within the sphere of accomplishment of a properly designed reduction gear. These advantages are as follows:

(*r*) *Economy of Weight.*—The reduction gear installation is but 40 per cent. in weight of the direct-driven arrangement.

(*s*) *Economy of Space.*—The installation of reduction gear arrangement can be effected in two-thirds the space required for turbine-driven engines. It is even possible to install the entire reduction gear arrangement on top of the condenser, and such a possibility best tells whereby less floor space would be required.

(*t*) *Improved Manœuvering Power.*—As compared with the direct-driven turbine, it is possible, with the reduction gear arrangement, to utilize nearly the full boiler pressure for backing purposes. The reduction gear arrangement permits the installation of a large as well as a slower moving propeller than can be effected with the direct-driven turbine.

(*u*) *Improved Economic Efficiency.*—With the successful development of the reduction gear there would not only come an efficiency accomplishment approaching that of the reciprocating engine at all speeds, but there would also be obtained the endurance advantage of the turbine for continuous sustained speed.

THE BOILER PROBLEM OF THE NEW BATTLESHIPS.

Since the discarding of sails and spars on board war-ships, the boilers have been well described as the lungs of the vessel. It has, therefore, been essential that naval designers should take advantage of every condition that would contribute either to the economic efficiency or to the evaporative output of marine steam generators.

In adopting an exclusive oil-fuel installation for the new battleships, the Navy Department took an exceptionally fearless attitude. The stand thus taken is certain to have a very determining effect upon the engineering efficiency and military value of our battleships. It may influence, in an indirect manner, the colonial policy of the government, for without colonial oil-reserve stations the field of operations of an exclusively oil-burning battleship may be somewhat limited.

From the naval standpoint of the oil-fuel question there are seven distinct features to be considered in connection with fitting these battleships with an exclusive oil-fuel installation:

1. *The Question of Supply.*—Measured in metric tons, the world's yield of crude oil is less than 5 per cent. of the world's coal-supply. In case there is any unusual demand for crude oil, it may be exceedingly difficult at such times to procure any considerable portion for fuel purposes, since the urgent demand for petroleum, naphtha, kerosene, and other lighter distillations of crude oil will undoubtedly seriously affect the possibility of obtaining a reliable supply for fuel purposes.

Fortunately for the manufacturing, maritime, and naval development of the country the oil yield of the United States in 1909 was 63.99 per cent. of the world's total production.

The distribution of our oil fields is also exceptionally advantageous for our possible naval needs, and in this respect our oil supply gives us a decided military advantage over every other naval power. The supply at our home ports ought, therefore, be assured, except under some unusual contingency.

2. *Cost.*—It has been estimated that it requires about $3\frac{3}{4}$ barrels of oil to produce the heat equivalent that can be obtained from a ton of coal. The average cost of a ton of coal at the mines in 1909 (throughout the United States) was $1.22. The average selling price of oil at the wells was 64 cents per barrel. It is, therefore, apparent that the cost of oil will approximate about double that of the cost of an equal heat equivalent of coal.

3. *Distribution and Transportation.*—Beyond the limits of our own shores the United States possesses less than one-half dozen oil-fuel stations where it would be possible for a fleet of our battleships to procure a full supply of oil fuel.

In time of peace there may be available, at many foreign ports, all the oil fuel that may be required by our war-ships. In time of war this supply will not be available, and therefore the field of operation of these ships may have to be confined somewhat exclusively to our own sea-coast.

The building of extensive tanks at both ends of the canal may help matters exceedingly, and this is a matter that is worthy of early and special consideration. It may also be possible to renew the oil supply from tank steamers.

4. *The Structural Feature.*—In order to give these new battleships the steaming radius possessed by the battleship Delaware, it may be found somewhat difficult to provide bunker space for the oil fuel that will be required. The construction of tanks adaptable for containing crude petroleum is a much more complicated and difficult problem than that of building bunkers for the reception of coal. In the commercial tank steamers the problem of storing oil is quite simple, since the number of tanks is comparatively few, and it is possible to readily reach the seam and riveting of all containing compartments.

Crude oil has also remarkable searching power, and the structural difficulties of containing a battleship supply is by no means easy of solution. Coal can be stored above, behind, and at the sides of the boilers, but oil cannot be stored in such easy manner. It may well be questioned if it will not be found somewhat hazardous to store oil in any double-bottom spaces within the fire-room compartments. The effect of even a small-sized shell bursting within an oil-fuel compartment may create havoc.

5. *The Thermal Efficiency of Oil.*—While the thermal value of oil is about $1\frac{1}{2}$ times that of coal, it requires intelligent operation to burn oil satisfactorily. On board ship, the piping of necessity must contain many bends, and therefore efficiency results that can be easily procurable on shore installations may be found very difficult to obtain afloat. The fire-room complement of the war-ship is constantly changing. As a rule, also, the combustion chambers of marine boiler installations are smaller in volume than it is possible to secure in many shore boilers.

The boiler efficiency results cited by Captain Dyson as having been obtained from a marine installation tested before going into the ship, wherein a boiler efficiency of 80 per cent. at low rate of combustion and of 69 per cent. at a maximum rate were secured, are not likely to be duplicated under sea-going conditions, since the shore tests were probably conducted by experts whose training and experience enabled them to secure results that are likely to be beyond the ability of the average naval firemen to obtain.

It is a matter of congratulation, however, that the Navy Department has just completed, at the Philadelphia Navy Yard, an experimental boiler or assimila-

tion plant for conducting experiments with liquid fuel. This plant is so named because its general construction assimilates to the fire-rim conditions on board a war-ship. There have already been installed at this plant two battleship boilers. Each of these boilers is of the latest design, and is capable of generating sufficient steam to develop over 3000 H.P. In the extent and character of its installation of appliances for experimental purposes the plant has never been surpassed. While it has required a somewhat heavy expenditure to effect this installation, the return to the government ought to be many fold. One is even conservative in affirming that, as a direct result of this installation, the shipbuilders of the country will be supplied with data that will enable them to produce results that they might not otherwise have been able to obtain.

6. *Mechanical Atomization of Fuel Oil.*—One of the distinguishing successes achieved under the direction of Rear Admiral Cone during the past few years has been the remarkable improvement as regards the mechanical atomization of oil.

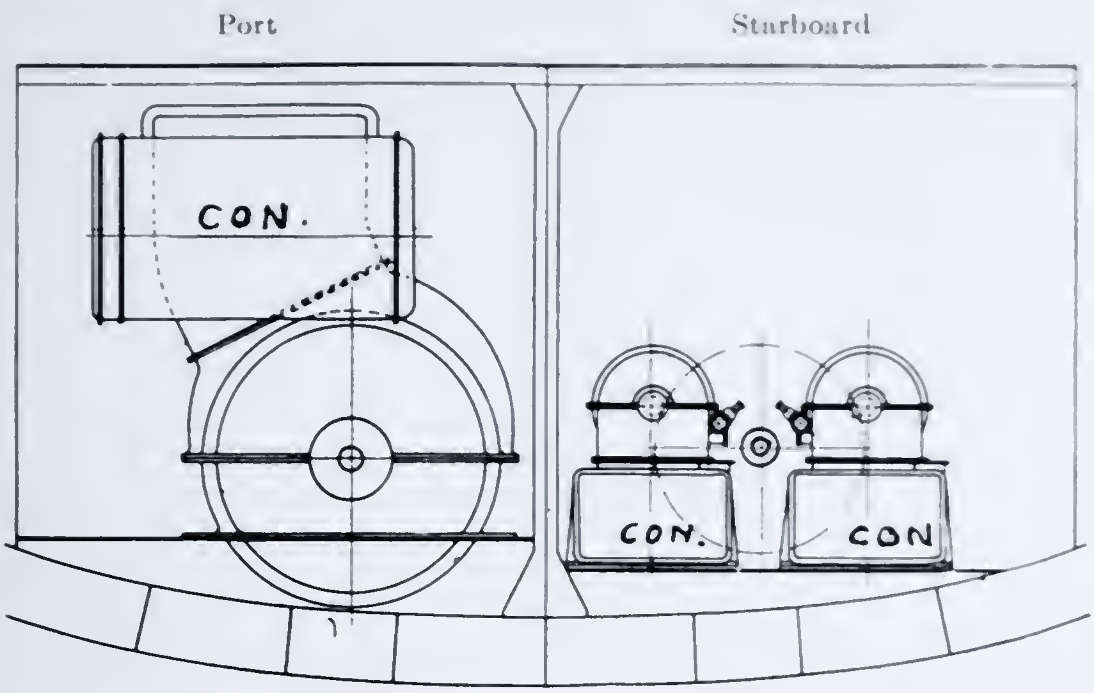
Under existing battleship conditions, there are almost prohibitive reasons against the use of either steam or compressed air for atomizing oil on board war-ships. The development of an efficient and reliable system of mechanical atomization of crude oil, therefore, constitutes a distinct and important step in naval advance.

The spirited and keen rivalry that exists between the fire-room complements of the numerous American torpedo-boat destroyers fitted with exclusively oil-fuel burning installation has likewise been a very important factor in developing an efficient system of satisfactorily forcing the consumption of crude oil by mechanical means.

7. *Safety of Operation.*—When it is remembered that the steam generators of a battleship must be kept in readiness to be forced beyond limits to which the boilers of the merchant marine are subjected, the fact becomes evident that there is a strong possibility of danger in the use of an exclusively oil-burning plant on naval vessels. As compared with shore installations for burning crude oil, the fire-rooms on the battleships are contracted, piping tortuous, and combustion chambers limited.

It is substantially only in the case of war-ships and fast ocean liners that the fire-rooms are subjected to heavy forced draft conditions. With any unexpected stopping of the blowers the possibility of serious flare-back becomes by no means remote.

Continual vigilance, exceptionally efficient supervision, and intelligent operation are, therefore, essential in securing economy and capacity as regards burning crude oil. Every check to danger should, therefore, be incorporated in the installation of a battleship's oil-burning equipment. As a matter of protection, there should, therefore, be installed in every direct line of oil piping under pressure a master automatic oil-control valve. On every auxiliary line of oil piping under pressure an additional subsidiary automatic control valve should likewise be fitted. Such valves are essential to the individual safety of the fire-room force and possibly of the ship. Their installation would also promote efficiency and economy, since the confidence that would be inspired by their installation would be reflected in the more reliable and satisfactory operation of the plant.



Section of frame 89 looking forward.

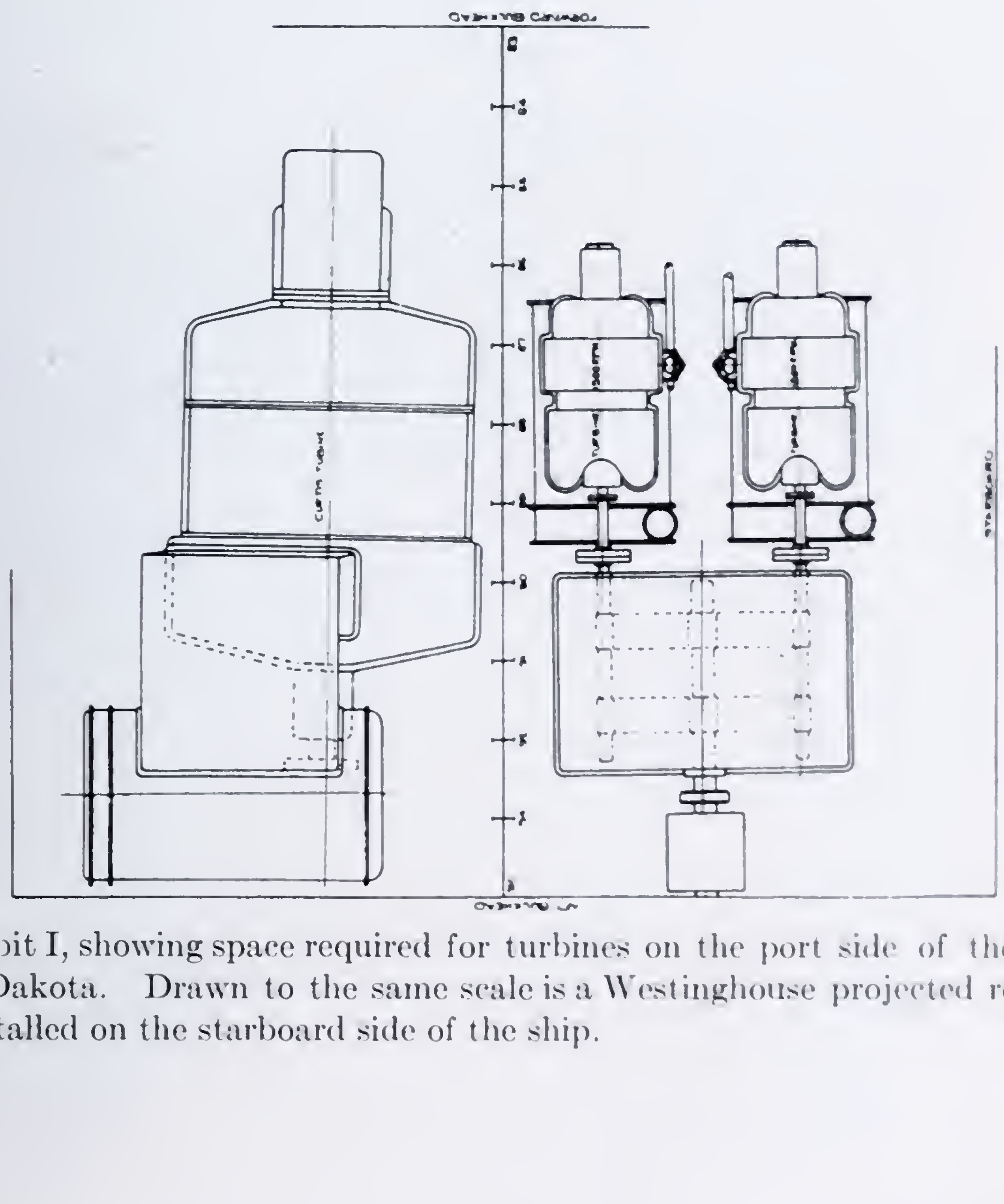
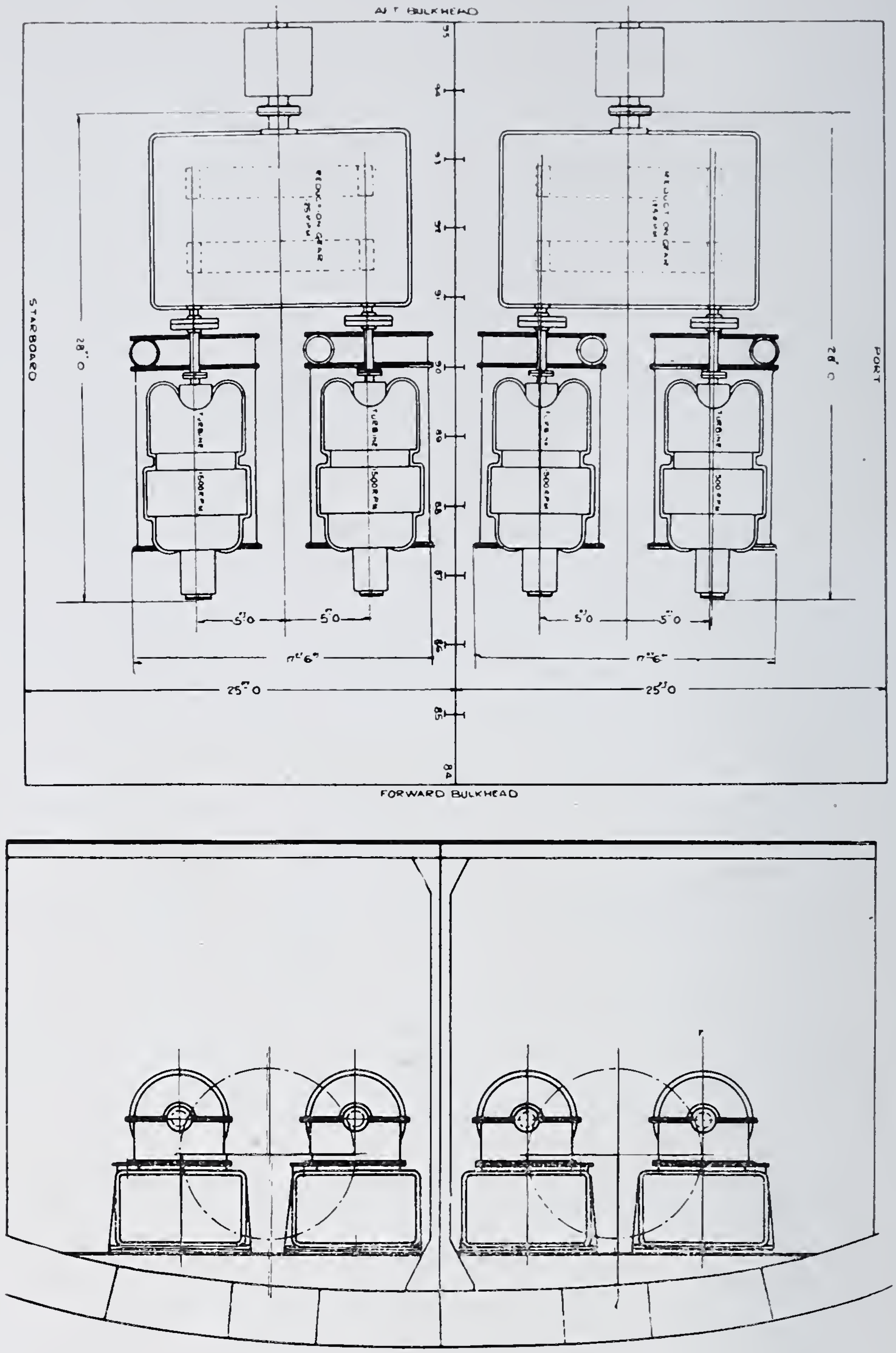


Exhibit I, showing space required for turbines on the port side of the U.S.S. North Dakota. Drawn to the same scale is a Westinghouse projected reduction gear installed on the starboard side of the ship.



Section of frame 89 looking forward.

Exhibit II, showing proposed complete emplacement of four turbines and two reduction gears for twin screws, U.S.S. North Dakota: H.P. each turbine, 7500; H.P. total for ship, 30,000; Rev. P.M. turbines, 1.500; Rev. P.M. Propeller, 150.

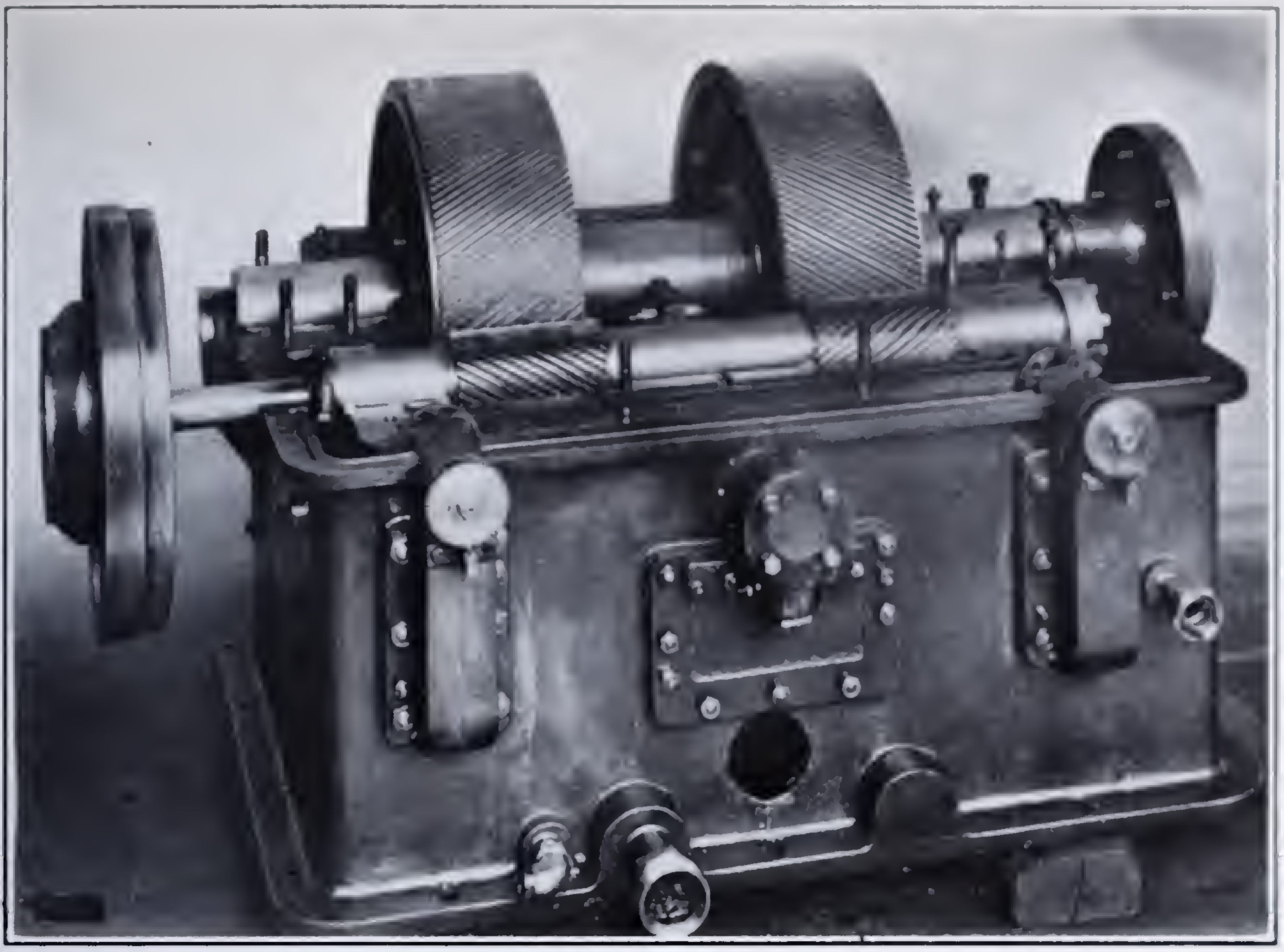


Exhibit III, showing construction of reduction gear, the caps of the pinion and gear bearings being removed.

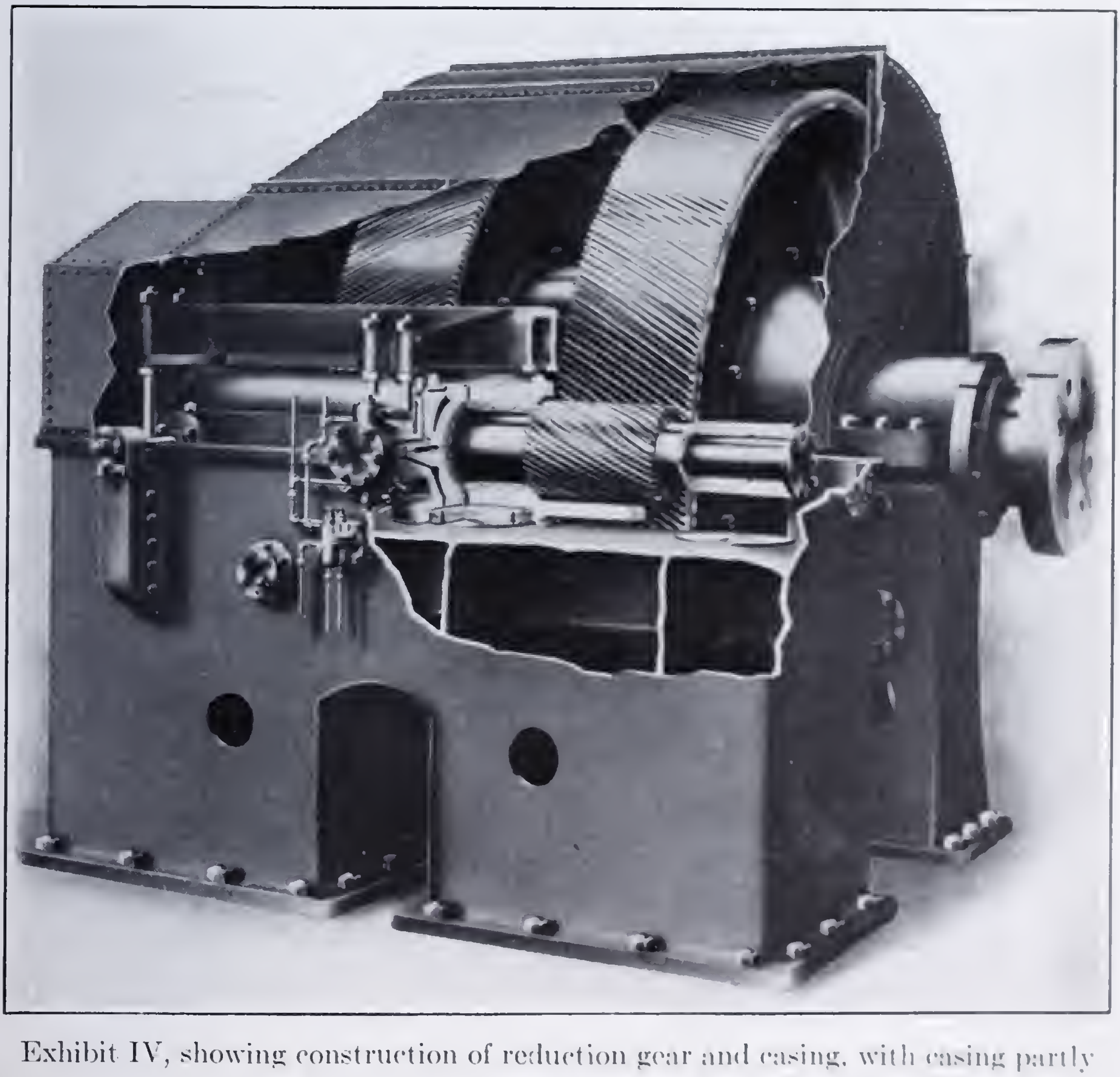


Exhibit IV, showing construction of reduction gear and casing, with casing partly removed.

Conclusions.

The important advantages of a reduction gear installation over an ordinary turbine arrangement, as regards economy of weight and space, can be best shown by drawing, to similar scale, an emplacement of a turbine actually installed and then showing a projected reduction gear emplacement the efficiency of whose installation will be guaranteed.

Particular attention is invited to the marked reduction in the amount of blading that will be required with a reduction gear, this saving in blading being estimated as at least 80 per cent.

A reduction gear arrangement is applicable to installations of varying power, from that required to operate a dynamo to that demanded in the propulsion of a modern Dreadnaught.

C. G. Curtis (Visitor).—Personally, I feel very much indebted to Captain Dyson for the remarkable analysis he has made of the steam-engine problems that have been presented to him, and I appreciate that he has devoted an immense amount of study and brought a lot of practical experience to bear on their solution. It seems safe to say that such information could not have been obtained from any other source throughout the world.

I am also greatly impressed with the improvements brought about in the reciprocating engines in naval vessels, mainly, if not entirely, by Captain Dyson himself. The reciprocating engine was thought, some years ago, to be about perfected, and it was not thought possible to make material improvements, but improvements have been made by Captain Dyson which mean a vast gain in economy, and at the same time a material gain in reliability. These two things impress me as constituting a remarkable advance in the steam-engine art.

Captain Dyson's paper and Admiral Melville's discussion have referred to the tests of three scout cruisers as being the only practical illustrations in this country of turbine as compared with the reciprocating engine vessels. In order to get a good idea of the turbine art today it is necessary to know something of what has been done abroad, and I am sorry to say that Americans are not prone to giving very much heed to foreigners, or at least to what they are doing. I think very few of the marine engineers of this country have any idea of the development that has been going on abroad, particularly in England and Germany. It is true that the scout cruiser Salem was less economic than her sister ship the Birmingham, at low power. But the Salem was built a long time ago, and when she was designed the demand for cruising economy did not exist. The contract was awarded upon certain guarantees that were very easy to meet, and the Salem was designed simply to meet those guarantees. She met those guarantees, and therefore fulfiled the objects of her designers. Since the Salem was completed, we have had two other similar vessels built, one in England and one in Germany, and it may be interesting to note the results of the trials in these cases. The only way to compare one vessel with another is to reduce the result in each case to the number of pounds of steam required to produce an effective or "towrope" horsepower. It is necessary to put it in this way because the efficiency of the propeller, as well as the efficiency of the turbine, has to be taken into consideration. For instance, we might have a very efficient turbine and a very inefficient propeller, which might show a poor result in propulsive horsepower.

The figures of the Navy Department show that the cruiser Birmingham, at 10 per cent. power, used 55.5 pounds of steam per effective horsepower for all purposes. Our British scout cruiser Bristol, tested about a year ago, required only 50 pounds, or 10 per cent. less steam, under corresponding conditions. Our German cruiser Mainz, built under much stricter guarantees of economy, required still less.

I will give the figures of water per effective H.P. for the main engines alone: The Birmingham required 40.3 pounds; the Bristol required 39.4 pounds; the German cruiser Mainz required only 33.5 pounds. In other words, she was about 16 per cent. more economic than the Birmingham at a 12-knot speed. The great problem is to meet conditions existing in battleships of 21 or 22 knots.

There is building in Germany today a battleship with three shafts that, at low speed, will be quite as economic as the United States battleship Delaware. Her steam consumption per effective horsepower for the main engines alone will actually be less than that of the Delaware.

The types of turbines that we are building today for the United States Government are radically different things from the turbines of the battleships North Dakota; they consume 30 or 40 per cent. less steam, and operate at lower revolutions, which means more efficient propellers.

R. L. Lovell (Visitor).—I cannot add much to Mr. Curtis' remarks, but I would call your attention to the fact that the North Dakota's turbines, referred to in the paper, were of an earlier type, and at the time the design was gotten out, about four years ago, the question of economy of battleships under cruising conditions had not been raised by the Navy Department, and consequently the turbines were designed to meet conditions then existing. To draw conclusions between these turbines and reciprocating engines which have had a long period of development is manifestly unjust to the turbine.

Since that time we have had no chance to demonstrate the advances that have been made in the art or to show what can be done as regards economy at low powers. In the latest United States battleships, bids for which have just been opened, we hope to have this chance. In these a design of turbine has been submitted upon which guarantees have been made of a less fuel consumption per knot from a speed of 10 knots upward than has been estimated for the latest design of reciprocating engine.

One other point, that of the question of repairs: It is true that for internal repairs the turbine ship usually goes into port, but, on the other hand, the liability of derangement with the Curtis turbines is very slight, and when this turbine does meet with an internal injury, this must be very severe to interfere with the working of the ship. In other words, an injury that would put a reciprocating engine out of business would hardly be noticeable in this turbine. We have had a case where one-third of the buckets of one turbine were out of commission, and the only noticeable effect was to slow that turbine down slightly, and in this condition the ship was able to make a knot better speed than her contract speed. Mr. Curtis' remarks covered what other ground I had in mind, and I have nothing to add to them.

H. T. Herr (Visitor).—I regret very much that I did not have more opportunity to read Captain Dyson's paper before coming to this meeting. I glanced through it hastily this afternoon, and from that survey and the reading of the

paper tonight I wish to second the remarks Mr. Curtis has made about the valuable data the paper contains and the conclusions reached by Captain Dyson.

In Admiral Melville's discussion of the paper The Westinghouse Machine Company is referred to in connection with the manufacture of a reduction gear which has been developing ever since the installation of the first gears in the U.S.S. Neptune. The development has followed more along the lines of the application of high-speed turbines to direct-current generators and centrifugal pumps by the use of an interposed reduction gear, than to the application of the gear to marine work.

The difficulty of making high-power direct-current generators and low-head centrifugal pumps to operate with high-speed turbines is well known to engineers, but these difficulties can be wholly overcome by the introduction of the Westinghouse Reduction Gear being built by our company. Some ten of these machines are now in service. They have so far been built in two sizes, *i. e.*, 500 K.W. and 1000 K.W. units for direct-current generation. The turbine runs at 3600 r.p.m., and in the 500 K.W. size a gear reduction of five to one obtains, and in the 1000 K.W. size a gear reduction of seven to one.

These machines are operating with entire satisfaction, and we have had absolutely no trouble with any of them, nor has any particular wear developed on gears or pinions. The machine longest in service has been operating continuously since April, 1911.

The gears used for direct-current drive are designed to transmit 1000 H.P. for the 500 K.W. size, and 2000 H.P. for the 1000 K.W. size, as the direct current generators are designed for 25 per cent. overload capacity.

The emplacement of the two 4000 H.P. reduction gears in the U.S.S. Neptune was designed with a gear ratio of a little over nine to one, giving at full power a turbine speed of 1230 r.p.m., with a propeller speed of 135 r.p.m. A comparison of the weights of the geared turbine machinery with the reciprocating engines on the Cyclops, the Neptune's sister ship, gives the following:

Neptune, total weight of two turbines and two sets of gears complete, 235,364 pounds; Cyclops, total weight of main engines, reversing engines, and turning gear, 586,000 pounds, resulting in a saving in weight by the use of reduction gearing of 350,636 pounds. On an equivalent basis, therefore, the weight of the main engines of the Cyclops is approximately 80 pounds per H.P., and that of the Neptune, 32 pounds per H.P. In addition to this, the turbine-gear installation occupies 10 per cent. less floor space than the reciprocating engines of the Cyclops, and less than one-third the head-room.

If, as Captain Dyson states in his paper, the engines of the Cyclops are designed along similar lines to main engines of battleships, it would appear that the turbine gear reduction arrangement should be installed on battleships for less than one-half of the weight of reciprocating engines, with a saving also in floor space occupied and a very material saving in the head-room.

The designs of the commercial machines which have been built by The Westinghouse Machine Company are based on the experimental gear which was built and tested to 6000 H.P. This experimental gear was built after the designs of Messrs. Melville and Macalpine.

Fig. 1 represents the application of low-pressure turbine reduction gear driving a 500 K.W. direct-current generator. The turbine runs at 3600 r.p.m. and the

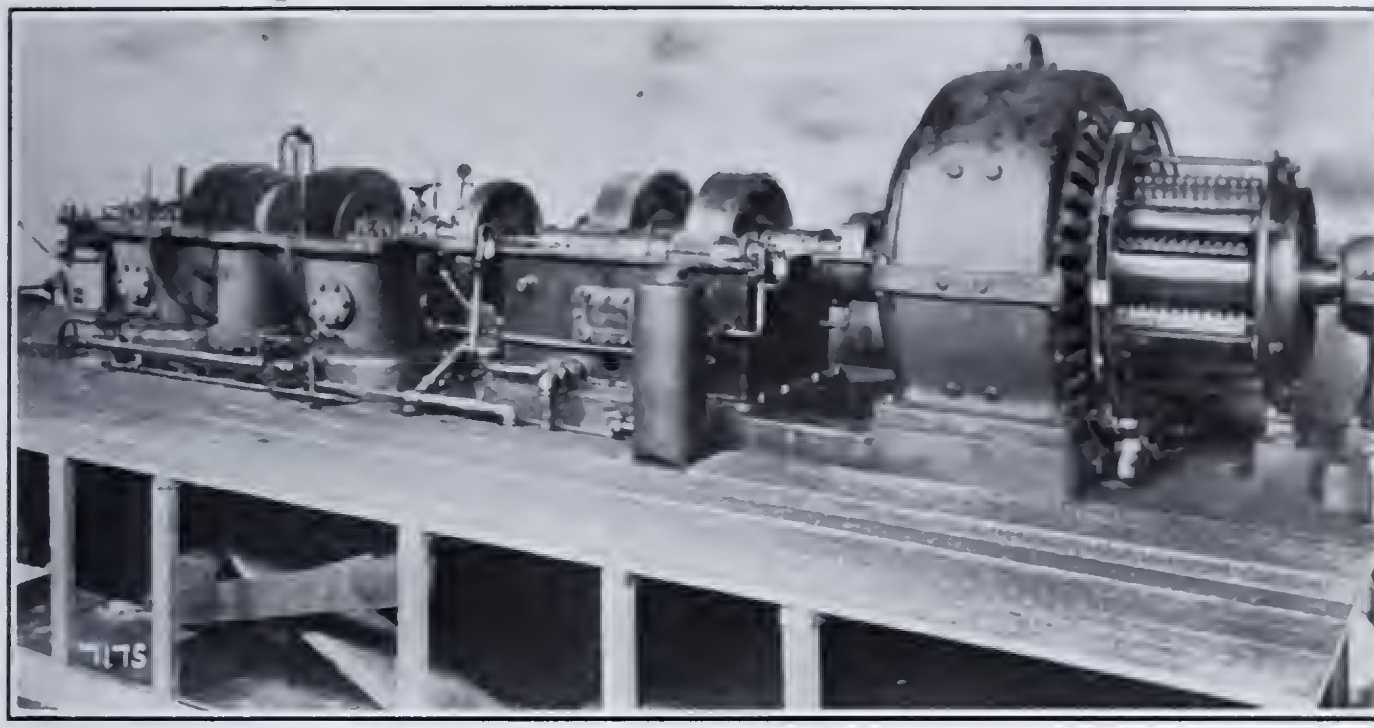


FIG. 1.

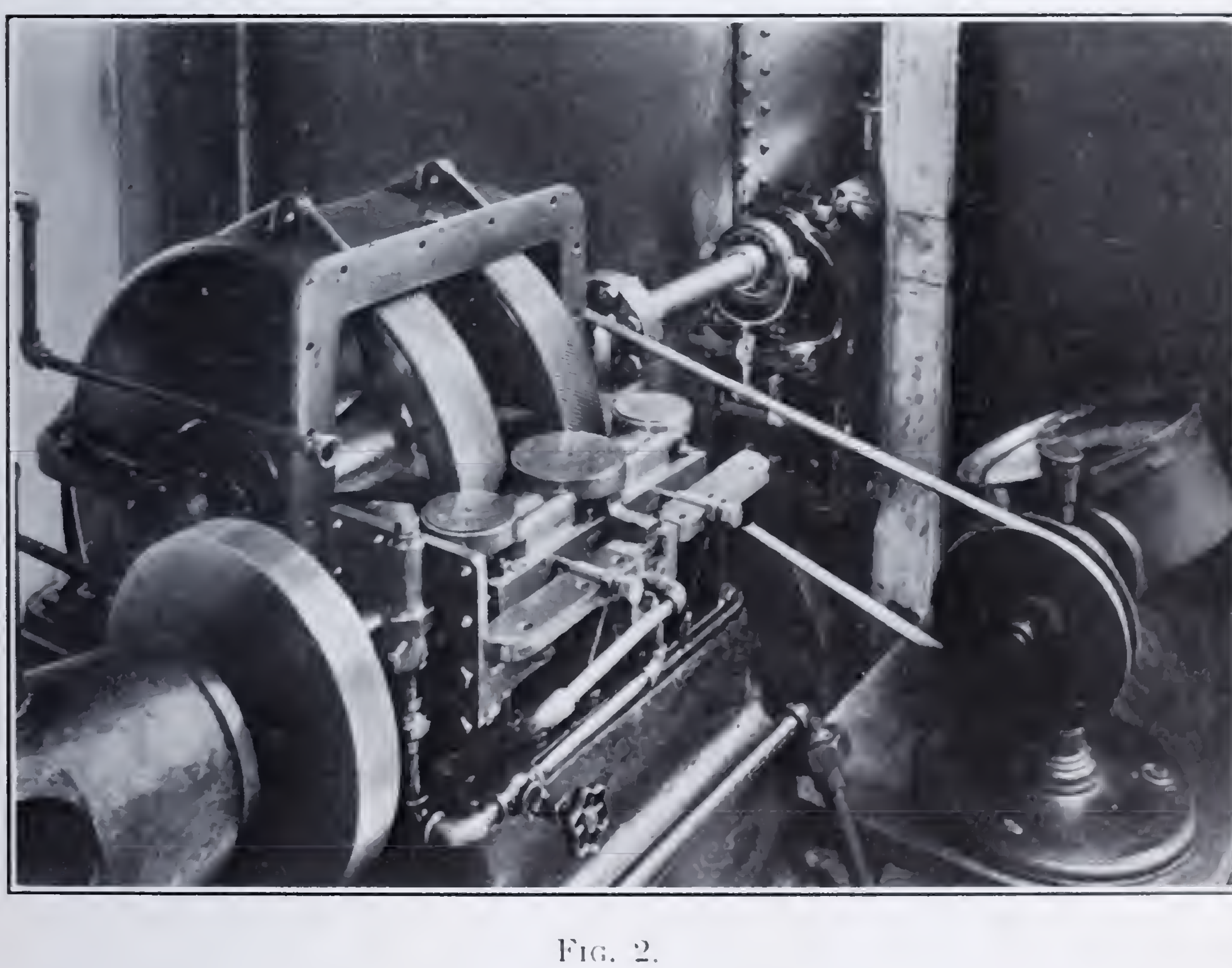


FIG. 2.

generator at 720 r.p.m. The pinion is 5.55″ in diameter, and the gear 27.93″. The total width of tooth faces is $17\frac{1}{2}''$; the pitch of the gears is $\frac{9}{16}''$. The pitch of the 2000 H.P. gear is approximately $\frac{3}{4}''$.

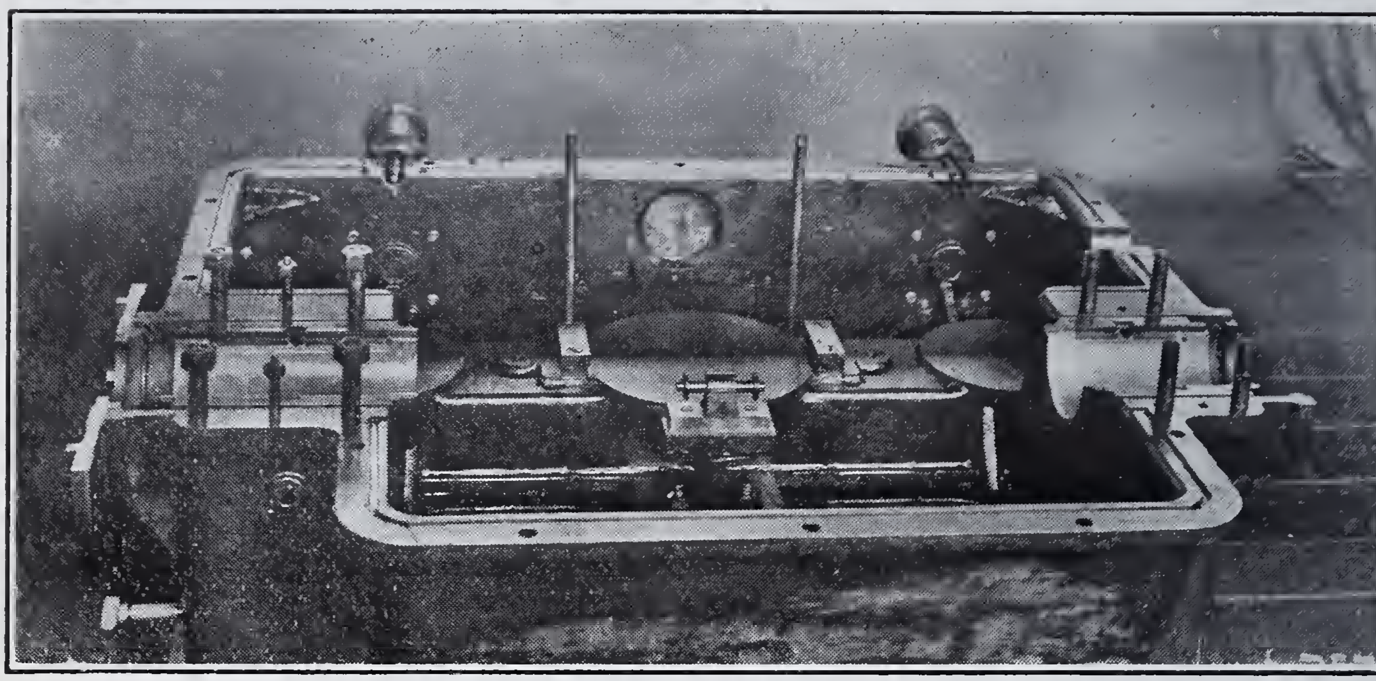


Fig. 3.

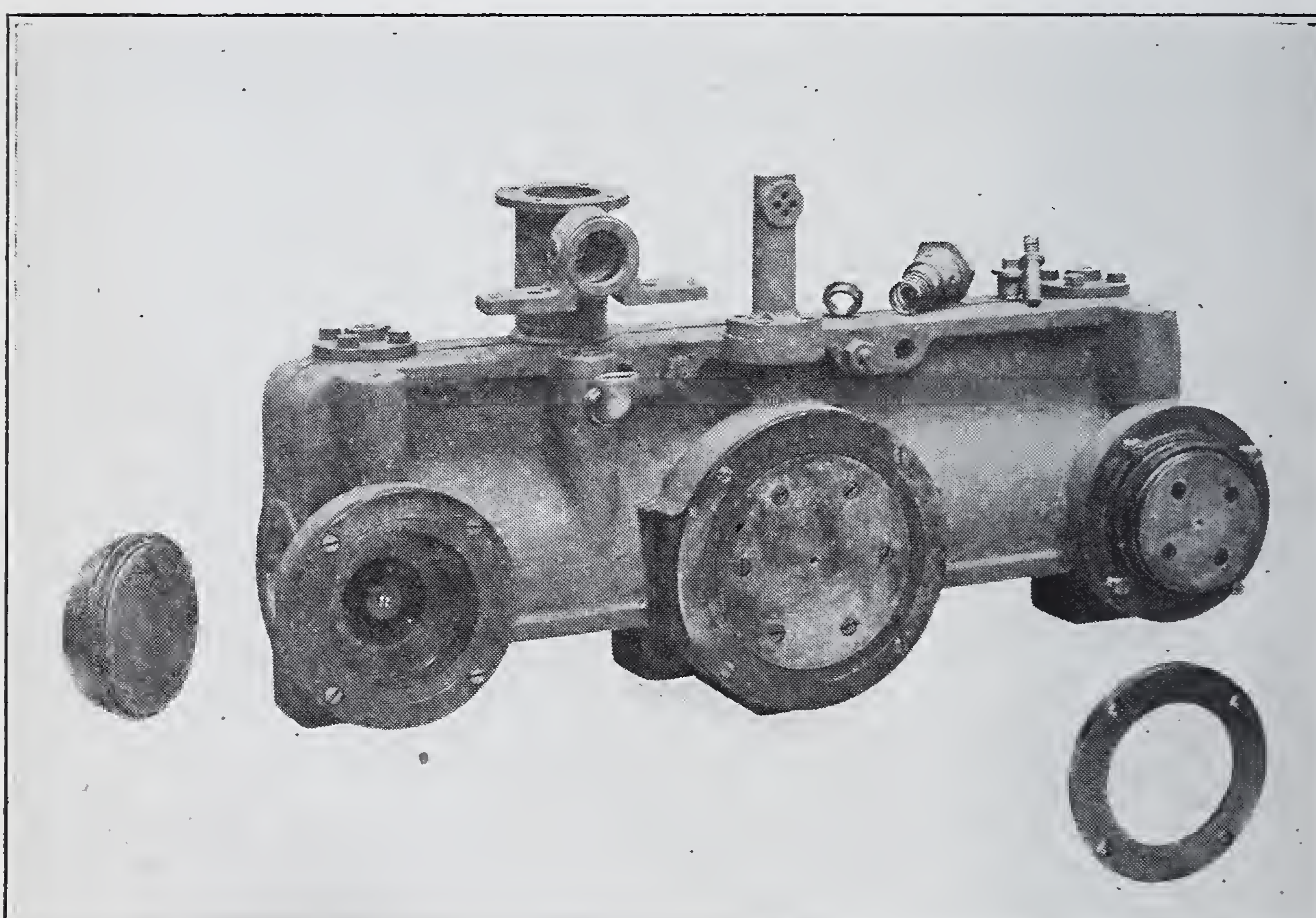


Fig. 4.

Fig. 2 is a picture of a model to show the principle of the application of the reduction gear to marine work. The turbine runs about 10,000 r.p.m., develop-

ing 50 H.P. The upper pistons supporting the floating frame are seen in the picture. This arrangement has been described in the technical press. The pinion frame is carried on an oil cushion, the pressure of which is automatically maintained proportional to the torque, consequently, by knowing the area of the pistons supporting the pinion frame, the pressure behind the pistons and the number of revolutions of the pinion, the horsepower is at once determined. As the area of the pistons is a constant, it is only necessary to record the revolutions and pressure under the pistons to get an instantaneous or continuous reading of the horsepower transmitted.

Fig. 3 shows the inside of the casing of 1000 H.P. reduction gear. The seating for the floating frame pistons is well known in this picture.

Fig. 4 shows the floating frame of 1000 H.P. gear with all the parts complete.

Some noise, of course, comes from large K.W. transformers. There is a high note in the operation of high-speed gears which, however, is hardly noticeable in the Westinghouse gear. I took a gentleman within 25 feet of one of the gears driving a 1000 K.W. direct-current generator carrying full load, and he did not notice the noise until I called his attention to the gear in operation by taking him up to it.

There were small errors in the worm-wheel of the gear-hobbing machine in the first gears that we cut. The larger the diameter of these gears, the more noticeable were the inaccuracies of the worm-wheel on the gear-cutter table.

The gears of the Neptune were the first and largest gears that we manufactured. The introduction of the Westinghouse floating frame arrangement materially deadened the noise from these inaccuracies and allowed the inaccuracies, so to speak, to slide over by the flexibility of the floating frame.

Since these gears were cut we have, in our own shop, recut the worm-wheels on our gear-hobbing machines, so that now all gears are practically alike. We simply cut them on the hobbing machine, set them up, and run them as they come from the gear-cutter. This we believe is practicable only with the floating frame. The pinions may be forged in our own shop and are made from ordinary carbon steel.

Paper No. 1108.

NOTES AND EXPERIMENTS ON EARTH PRESSURES.

JAMES C. MEEM.

(Visitor.)

Read November 18, 1911.

It is believed that in no branches of engineering are we so deficient in knowledge as in those relating to the pressure, resistance, and stability of earth; and yet few structures can be designed or erected without taking into some account their relation to one or the other of these factors. It appears to be a generally accepted fact among engineers that the ordinarily used formulæ and data relating to these factors are in all cases subject to some qualification and modification, even by the most extreme theorists, while many engineers who have had occasion to get more closely "in touch with the ground" are convinced that the fundamental principles on which the formulæ are based are materially or radically wrong. It is further believed that the laws governing the pressure, resistance, and stability of earth may be determined and formulated with almost as great accuracy as those relating to the properties of steel or cement. To this end it is essential that experiments first be made on a scale large enough to be conclusive with all classes of ground from peat to rock, containing moisture in varying degrees from zero to complete saturation. Until such experiments are so made engineers will continue to disagree, and observations and experiments made in support of the old theories, or the so-called practical ideas, will be looked upon with suspicion by partizans of the opposite school.

This paper will describe some experiments on a small scale which the writer has made, and also some experiments made by others, which seem to point to a conclusion, and finally it will note his own conclusions from these experiments and from observations made under practical conditions. The apology for repeating much of the matter, which is here presented in a different form only, is that by its continued reiteration it is hoped to stimulate interest in these factors, so that some man or body of men may eventually, by experi-

ments on a large scale, determine definitely the laws relating to the pressures of earth. Some of the commonest sources of error in connection with the laws relating to earth pressures are due to the fact that experiments have been made on small percentages of the whole area, such as diaphragms or pistons thrust through sheeting, or walls of coffer-dams, and also to the fact that many of the observations are often made after the failure or slump has taken place. In the latter case the velocity of flow of the water or aqueous material is often used without qualification as a factor in arriving at a determination of the static pressure, while the plunging of a piston through a hole in sheeting against which there is perfectly dry sand will give the same resultant pressures no matter what the elevation. This can be noted in experimenting with an hour-glass on a large scale through which the sand runs uniformly and at the same rate at the beginning as at the end of the experiment, while if the experiment be made on a larger scale, it will be found that increasing the pressure on top of the sand, or largely increasing the quantity, will not change the rate of flow. Some time ago the writer's attention was called to a London publication describing some experiments on dry sand made in 1873, and he had made an apparatus for trying the one here described, the results of which seemed most interesting. The apparatus consisted of a 2-inch pipe, about 18 inches long, with means for attaching to the machined face of its lower end a tissue-paper covering. With one foot of dry sand in this pipe a piston bearing on it would sustain any ordinary load, such as the weight of a heavy man or the blow of a sledge hammer, if not repeated often enough to jar and thus tear the fragile paper. This experiment is a simple one, and the apparatus can be constructed by an ordinary pipe-fitter, and its results are so interesting and conclusive that it is called to the attention of those who may care to make it. It seems to point conclusively to the fact that pressure is transmitted laterally through sand, and bears out the observation sometimes made on grain bins, that the bottom does not carry the full load of the superimposed material, and that this is the case even where the grain is flowing out at the bottom. The underlying principle is that the pressure on the piston is transmitted laterally to the sides, probably along planes parallel to the angle of repose, with the result that the friction is operative in direct ratio to the pressure, so that the increase in the pressure—after a certain depth has been reached—

does not add to the pressure on the pipe bottom. There appears to be no reason to doubt that an experiment similar to that made here in absolutely dry sand on a small scale would give proportionately similar results if made on a scale of any magnitude, in which all the ratios were maintained, and assuming that the retaining medium at the bottom was capable of sustaining the bottom loading up to the point where the depth became sufficiently great to form a cushion, over which the lateral thrust would tend to make the rest of the load self-sustaining. Keeping in mind this experiment in its relation to those next described, it will be less difficult to understand their purpose and results.

The writer has long believed that all material other than fluids possessed arching properties, and that even dry sand could be formed into a sustaining arch, providing the bottom portion, forming what might be called a natural centering, was sustained either by extraneous methods or kept from disintegrating by other means. In short, he saw no reason why an arch could not be built of bags filled with dry sand, assuming there was depth enough to key and spandrel to take the thrust and provide against distortion. He also felt that if the so-called centering of loose sand in a dry sand arch could be sustained from above, it would conclusively prove that the sand was not only capable of doing so, but did arch itself. He caused to be constructed a small box without a bottom, except for two cleats along the outside edges of two parallel sides; four bolts were run through a false bottom somewhat larger than the bottom of the box itself, with gaging nuts intended to bear on large washers resting on top of the sand in the box. It was found that the box (a 9-inch cube) could be partly filled with sand up to five or six inches, and, on tightening the nuts down on the sand and thus bringing the false bottom tight against the bottom edge of the box, that the box could be lifted and carried about without the slightest danger of collapse. The experiment was later tried with wheat, the results being similarly satisfactory. There seems to be no reason to assume that if this experiment was successful, even on a small scale, with dry sand and wheat, in which there was no cohesion, that its principle would not be applicable on an indefinitely larger scale. The difficulty of making it on a scale large enough to be finally conclusive is very evident, and lies largely in its almost prohibitive cost. An opportunity was given, however, to make a similar experiment on a sand arch with a span of three feet.

The apparatus in this case consisted of a box 4 feet high, 7 feet long, and 3 feet wide, crossing an opening 3 feet wide, over which the bottom was omitted, the space being closed by a false bottom covering it, and through which long bolts were erected, their tops engaging nuts and large washers, as in the smaller experiment, intended to bear on the sand. The box was then filled with normally dry sand and gravel as it came from the trench. The bottom was temporarily supported and the nuts were driven hard on the washers. It was found difficult to bring the bolts under heavy tension, owing to the impracticability of getting the sand compact enough to support the pressure on the washers, and for this reason the experiments were not successful until a depth of 41 inches had been reached between the bottoms of the washers and the top of the false bottom. The temporary supports being removed in this instance, the bottom dropped some two inches, due to the further compacting of the sand, the two-inch face exposed being kept from disintegration by the cohesion of the material in its natural condition. After some two or three hours the arch was loaded with about 600 pounds, live load, and under this it sank two inches more, or to a total of four inches. This load was then removed, and after another hour the exposed four inches was disintegrated by scraping out a handful of sand, when the arch instantly collapsed. It is believed that with compactness equal to that of earth in its natural bed a depth of much less then 41 inches would have been ample to sustain the arch. The practical application of this is that there is always some portion of a sand or earth arch which is dead weight, and which may be called "centering." The author has arbitrarily assumed that the apex of this area is at the intersection of the planes of repose, springing from the haunch lines of the arch, and intersecting above the center of the arch, and that all material below these planes must be supported by the false bottom, as in the experiment, or by bracing or structural roofs in practice. Above this there is assumed to be an arch formed on this centering with depth of key sufficient to make it self-sustaining, and so on to the surface of the ground. It is fair to assume that while all that below is dead weight and that above is self-supporting, some portion of this latter must, for safety, be carried by the centering or roof. The writer has assumed further that the height of a point above the roof of a structure, at its center, above which the ground is self-supporting, is measured by the tangent, at the center, of an angle between the horizontal and a line or plane which bisects the angle

between that of repose and the vertical. If, then, from this point lines or planes are drawn parallel to the angles of repose, the area vertically over the tunnel between these lines or planes and those of repose is assumed to constitute the arching area, the lower half of which, together with that already noted as centering or dead weight, is assumed to be carried by the structural roof and the upper half to be self-sustaining. This may be expressed in another way by assuming that all the area below these lines or planes, intersecting over the center and bisecting the angles between that of repose and the vertical, is carried by the centering or roof. As a practical example, assume that ϕ is the angle of repose of material being tunneled for a structure, of which L is the outside diameter or width.

Then the load per lineal foot being $W\rho$, and assuming W = weight per cubic foot of the material, and $\frac{L}{2} \times \text{tang.}\ (\phi + \frac{90°-\phi}{2}) = \frac{L}{2}\ \text{tang.}\ (45° + \frac{\phi}{2})$ to be the vertical height above the tunnel roof where the planes intersect, and above which the material is fully self-sustaining;—

Then the load per running foot is equal to—

$$W\rho = W\,\frac{L \times \frac{L}{2}\,(\text{tang.}\ 45° + \frac{\phi}{2})}{2} = W\,\frac{L^2}{2}\ \text{tang.}\ (45° + \frac{\phi}{2}).$$

An essential condition of this reasoning is that the flatter the angle of repose, the greater the lateral thrust, and, therefore, the less the weight imposed on the roof of a tunnel structure in normally dry material of a smaller angle of repose than in similar material whose angle of repose is larger. Objection has been raised to it from the seeming fact that if carried to the extreme limits of zero and 90-degree angles of repose, it could be proved to be fallacious. It has been suggested, for instance, that under this reasoning rock with an angle of repose of 90 degrees could not be tunneled without carrying the entire superimposed weight, while water with an angle of repose of zero could be tunneled without difficulty and with very little weight coming on the structure. These two cases are not applicable, in that rock, *i. e.*, solid rock, has no real angle of repose, and may be cut vertically as readily as it can be tunneled, while water is not a solid material or composed of solid aggregates, and in any case it can neither be tunneled nor cut vertically. Applicable illustrations must be:

For a vertical angle of repose some solid aggregates, such as cubes of marble superimposed directly above each other; and for an angle of repose equal to zero, iron filings drawn horizontally by a powerful magnet.

While these types are not found in practice, they serve very well as illustrations, for it can be readily seen that in one case there would be practically no friction and the whole weight would be carried on the tunnel roof, while in the other case there would be no weight, and designers of tunnels in such materials could disregard largely any provision for weight on the roof. On the other hand, the cubes of marble could be cut vertically within reasonable limits without inducing side thrust, while the filings would give full horizontal thrust against any face or sheeting interposed vertically.

Next as to the question of lateral thrust against sheeted faces, or against walls or structures. Assuming that the above reasoning is correct for tunnels, then for trenches the conditions are practically reversed, as noted heretofore, *i. e.*, in the dry materials, those which give maximum thrust give minimum weight, and vice versâ. There is no reason to suppose if material is open-cut for a structure instead of tunneled, that the stresses in the material outside the sheeting lines will be materially changed because of the substitution of sheeting and bracing for the natural earth; that is, the thrust of the material will be transmitted through the braces, and thence laterally downward into and through the material on the other side. The resistance to this thrust through the bracing into the material will be transmitted through the haunches of what may be termed a series of arches, which will lie between planes which have been assumed to be approximately parallel to the planes of repose. These will, in turn, resist the tendency of the wedge, of which they are a part, to slide along the plane of rupture toward the toe, the condition of stability being the tightness of the bracing holding it in place. It may be added, in parentheses, however, that, failing to make the sheeting and bracing absolutely tight, it will be made so automatically by the gradual settling down of the material, providing the settlement does not come with sufficient force to cause shock or collapse. A series of independent, dependent, and finally interdependent arches or sections of arches are thus formed, whose line of thrust, as stated, is assumed to be along the planes of repose, and the measure of whose thrust is proportional to the cotangent of this angle of repose, and whose area lies between the vertical and a plane bisect-

ing the angle between the vertical and the plane of repose. That is, let—

ϕ = the angle of repose, and $\frac{90°-\phi}{2} = \beta$ = the angle between vertical and plane of rupture, and h = the height.

Then Area $= A = \frac{h}{2} \times h$ tang. $\beta = \frac{h^2}{2}$ tang. β.

Its thrust at any point $= T\rho = a\,W \cot \phi$.

W being Wt. per cubic foot of material and a being area of material at any point causing thrust $T\rho$

Or the thrust over entire area $= T = A\,W \cot \phi = \frac{h^2 \cot \phi \text{ tang. } \beta}{2}$.

Obviously, if this thrust is due to a series of arches, its point of application will be through its center of gravity, which will be two-thirds of h above the toe, and the moment per lineal foot tending to overturn a wall or structure will be

$$M = T \times \tfrac{2}{3} h = \frac{h^3}{3} \text{ tang. } \beta. \quad \text{Cot } \phi.$$

So far, consideration has been given only to those materials normally dry, *i. e.*, as ordinarily found under normal conditions, where not saturated or submerged, and commonly called dry ground. Saturated materials will now be taken up under the head of Wet Ground, and will include only ground which is temporarily or permanently submerged, so that the water therein or the ground itself is under hydrostatic pressure. For a clear understanding of materials in this class three subdivisions will be made:

(*a*) Those materials in which the voids are defined, such as gravel, gravel and sand, or sand in which there is not a large percentage of soft material. Material of this class may be called "firm ground."

(*b*) Those materials of which the voids are filled with fine material, largely in suspension in the water, such as sands mixed with silt or clay. This may be called "semi-aqueous material."

(*c*) Those materials, such as fine silt, very soft clay, very wet, freshly mixed concrete or quicksand, or any material which flows under normal pressure. These may be called "aqueous materials."

Of these materials, the last, or aqueous, may be left out of consideration, as the laws applicable to them are obviously the same as those belonging to water itself. In this connection it should be noted that the hydrostatic pressures resulting from these materials should be figured on the specific gravity of the carrying fluid and not

on weight; that is, for instance, wet concrete will not give a hydrostatic pressure due to the weight of 140 pounds, but of $62\frac{1}{2}$ pounds per cubic foot, due to the fact that the solid particles in suspension derive buoyancy from the presence of the water until they settle down and cease to exert pressure, except as a solid.

Consideration of Class A materials, or firm ground, will next be taken up, and may lead to a better understanding of the conditions governing those materials of Class B.

In connection with the sand arch experiments first described, an additional experiment was made. A box of 9-inches cube was used, similar to that described, with false bottom, except that the front was made of glass. This box was filled with sand to a depth of about 5 inches, the washers keyed down tight, to insure that the false bottom was pressed up tight against the open bottom of the box. Water was then poured into the box, and even after saturation was complete, as observed through the glass side, there was no failure or collapse when the box was lifted, with the water standing as high as two inches above the sand. This demonstrated conclusively that in small volume at least the pressure of water does not destroy the arching properties of sand.

In the second experiment made, the apparatus consisted of a hydraulic chamber some 9 inches in diameter and 18 inches high, whose top contained a collar through which went a piston some 24 inches long and 3 inches in diameter. Connected to this chamber was a nipple connecting by copper hydraulic pipe to a pressure-pump and gage. The piston was first lifted and held about 6 inches off the bottom; water was pumped into the chamber, and the pressure required to lift the piston further was noted. This was repeated and was found to be uniform. A table standing on 8-inch legs, with a hole through which the piston fitted loosely, was next put into the chamber. This table contained pipes, so that water could circulate from above the table to below it, and the sides above the table around the pipes were filled with sand to a depth of some 6 inches. It is readily seen that the area of piston against which the water impounded was not reduced, but that the friction of the sand bearing on the piston could be measured if appreciable. As the piston was a polished surface, it was found that this friction was negligible, *i. e.*, in a gage registering pounds only it could not be measured. The table was then removed and the bottom filled with sand to a depth of 6 inches, the piston put in place bearing on the sand, and 6 inches more sand put

in surrounding the piston. It is seen that, neglecting friction, if the area of the piston's base was not reduced by its contact with the sand, it would rise under the same pressure as that required to raise it in clear water. A series of tests proved, however, that it required approximately double the pressure to start the piston from that required to continue to raise it after it started, due to the fact that, on the formation of a water-pocket between the piston's bottom and the sand, the pressure of the water on the full area of the piston was brought to bear, whereas when in contact with the sand, its area was reduced by the proportionate amount of the contact. It is believed that an experiment along these lines on a much larger scale will be of great value in clearing up a mooted question among engineers. It must be admitted, even in the case of the smaller experiment, however, that one of two conditions must have obtained—either the water, through numerous minute channels, was in contact with the base of the piston, in which case fluctuations of pressure would immediately be transmitted from the clear water at the top to the base of the piston, and the fact that the piston did not rise until double the pressure had been exerted thus showed a reduced area; or, on the other hand, it must be admitted that there was no continuous contact of water, and that "leads" had first to be opened before pressure could be transmitted to the piston's bottom. If the latter be true in so small a chamber, it must undoubtedly be true in practice, that a submerged structure is not under buoyant pressure because of the fact that the channels of water leading from the clear water to the structure are not continuously in contact. The writer prefers to believe that the first condition is true, and that continuous channels lead from the structure to the clear water, these channels being independent in a measure of the so-called columns of sand in between. For instance, if a chamber be taken containing a piston whose specific gravity is less than that of water by the smallest fraction, and it is assumed that its polished bottom is in contact with the polished bottom of the chamber, it will not, of course, be buoyant when the chamber is flooded. If, again, a series of smaller rods, with polished tops, perfectly flush with each other, be wedged into a pipe, and if a piston, as described, be set on them, it will not rise because the buoyant area is not sufficient to cause it to do so. The writer holds that the same reasoning is true if sand, packed or wedged into the bottom of the pipe, be substituted for the rods; and he believes that the experiments noted have shown that a piston or structure resting on or

buried in sand has what may be termed its buoyant area reduced by reason of that contact. Some reasons for this assumption, aside from the experiments, will be noted later. As to the application of this theory to practical conditions, the pressure over the roof of a subaqueous tunnel in firm ground, or Class A materials, will first be noted. In such materials there will undoubtedly be two classes of pressure—one wholly aqueous or hydrostatic, and the other due to the solid material. If it is assumed, for a better understanding, that the material is coarse sand with a percentage of voids = s, with a normal angle of repose it should first be noted that material of this character will have its angle of repose increased by reason of its submergence, and for safety it may be assumed that it is 30 per cent. greater than when normally dry. The thickness of solid material at which the arching properties would be effective would be

$$\frac{L}{2} \text{ tang. } \alpha$$

above the springing line of a tunnel if circular, or above the roof if flat, L being the greatest outside diameter or width of roof, and other factors being as follows: ϕ = angle of repose

$$\alpha = \phi + \frac{90^\circ - \phi}{2}.$$

Assuming then a depth of material d as equal to or greater than

$$\frac{L}{2} \text{ tang. } \alpha,$$

the conclusion is that all solid material at and above that elevation is carried by its own arch, and as well the pressure of water on all material, which, by reason of continuous contact to the tunnel, is assumed to be the equivalent of a number of solid columns. Between these columns the water pressure acts independently, *i. e.*, for the weight per lineal foot ($W\rho$), on a tunnel of outside width (L), we have, assuming a depth of water (D) and a depth of material (d) of the class and under the conditions noted, W being the normal weight per cubic foot of the solid material and 62½ pounds being the weight of water:

Assuming a percentage of voids in the material = s, as above:

then $W\rho = W\delta \dfrac{\left(L \times \frac{L}{2} \text{ tang. } \alpha \right)}{2} + 62.5 \text{ D s L}$

or $W\rho = W\delta \left(\frac{L^2}{4} \text{ tang. } \alpha \right) + 62.5 \text{ D} \times \text{s L}$, for condition as noted above, where $d > \frac{L}{2}$ tang. α.

Where $d < \frac{L}{2}$ tang. α

$$W\rho = \text{W L d} + 62.5 \text{ L} (\text{D} - \text{d} + \text{s d}).$$

That is, the assumed solid columns bearing on the tunnel transmit to

the tunnel the added weight of the water bearing on them, but not the weight of the water which they displace, since they cannot bear on the tunnel at the same time as the water. If it were assumed that the excess weight of the columns over that of the displaced water bore on the tunnel, then

$$W\rho = (W - 62.5)\ L\,d + 62.5\ L\,D$$

It is seen from the above reasoning that if a tunnel of a width of 20 feet outside with 50 feet of covering, the pressure on its roof is not so great as one in which the covering is 40 feet, assuming equal depths of water to the roof.

Comparing the two last formulæ, we find in a tunnel with

$$\begin{aligned} s &= 40\% \\ L &= 20 \text{ feet} \\ d &= 40 \text{ feet} \\ D &= 90 \text{ feet} \\ W &= 100 \text{ lbs. per foot, then:} \\ W\rho &= 162{,}500 \text{ lbs.,} \end{aligned}$$

or a little over 4 tons per square foot, while in the second instance,

$$W\rho = 142{,}500 \text{ lbs.,}$$

or a little over $3\frac{1}{2}$ tons.

The writer prefers to consider that the former instance is more in accord with the correct theory and safer in practice.

As to the pressure against a sheeted face, coffer-dam, or retaining wall, here again there are independent pressures to consider. First calculate the pressure of the solid material against a wall, as noted, bearing in mind that such material, when submerged, will stand at a steeper angle of repose, and, therefore, the thrust due to the pressure of this material is lessened by its submergence; then calculate the water pressure separately, assuming that it acts in the same way as does water alone, except that it is diminished by 60 per cent. if 40 per cent. voids are assumed. This should not be taken to mean that the pressure at any point is only 40 per cent. of what it normally would be, but that the area over which the pressure is distributed is only 40 per cent. of the whole. The sum of these two independent pressures constitutes the total pressure against dam or structure, and, with proper qualifications as already noted, the pressure against any given point.

Coming now to the consideration of Class B, or semi-aqueous

materials, which constitute by far the larger class, the writer is of the opinion that they should be treated in the same way as firm, or Class A materials, except that the larger proportion of aqueous material should be given due weight. Thus: If such a material when dry is found to contain 50 per cent. of sand and 50 per cent. of clay or finely divided material and 20 per cent. of voids, then it should be treated, when saturated, as a material of which 50 per cent. was solid and 70 per cent. was aqueous; that is, an excess percentage allowance for the aqueous should be made before proceeding as heretofore noted. The determination of these factors need not in any case be left to guess-work or chance, but can be definitely established, as can also the angle of repose when the material is dry and when it is wet. With these factors and others determined by experiments on a large and comprehensive scale the engineer can proceed with safety along the general lines proposed or as modified by the results of the experiments.

As to the question of buoyancy, and assuming that the experiments cited have been conclusive, there are still many elements for consideration before their application to all cases may be deemed final. Even purely aqueous material does not render structures submerged in it buoyant. A man, for instance, will sink in quicksand because what may be called the area causing buoyancy is reduced by contact with solid material. It is also well known that tunnels under the North and East Rivers were not buoyant, whereas the material under the North River was at times so aqueous that during construction it tended to flow in almost like water, and in many cases the doors were not opened even for the advancement of the shield. In the semi-aqueous material of the East River the tunnel, though theoretically buoyant, always sank when the material around it was disturbed, and the history of the North River tunnels showed the same condition. On the other hand, floors have been known to burst up under pressures, while other floors, admittedly not strong enough to resist full pressure over the whole area, have done so without any evidence of failure.

In considering the subject properly, study should be made of structures fulfiling one of the five following conditions in materials of one of the three classes noted:

(1) Structures wholly buried.

(2) Structures partially buried.

(3) Structures whose floor areas are an integral part of the foundation.

(4) Structures whose floor areas are not an integral part of the foundation.

(5) Masonry dams.

The history of tunneling, to which some reference has been made, and of all braced structures, conclusively proves that buried structures are not buoyant.

It is believed that a partially buried structure can be designed to resist buoyant pressure providing it is designed with a small margin of excess weight above that shown under the theory noted in this paper. As, however, no engineer will design a bridge without a reasonable factor of safety, so no one should fail to provide against contingencies even though convinced that they may not arise. Therefore the writer concurs with those who are of the opinion that the design of partially buried structures should provide against full upward pressure.

As to those floor areas which are an integral part of the structure foundation, it is readily seen that, being part of the foundation, they must bear on the solid material and must, therefore, have some of the area exposed to upward pressure reduced.

On the other hand, those floors not forming a part of the foundation may be called upon, in certain classes of material, to resist full upward pressure.

As to the masonry dams, it is not possible to consider such structures resisting full or even a large percentage of full upward pressures, unless built on materials so porous that their being built thereon would be an absurdity.

In considering all these conditions, it must be noted that the conditions under which a structure is built, or, rather, those obtaining during its construction, are vastly different from those which eventually obtain, *i. e.*, in connection with subaqueous tunneling it has been often noted during construction work, owing to incidental loss of air and stirring up of the material, that the material was in a "soupy" condition, whereas soundings before the beginning of work and the stability of the structure afterward tend to show that the material before being disturbed was firm and hard, as it likewise became after the disturbance ceased. It is also well to note that water through the ground is constantly flowing along minute channels, and that as it flows into and through an abnormal void, it finally fills it with the finer material obtained elsewhere. It is probable, therefore, that the abnormal voids will not long continue to exist in contact

with any structure, except in possible isolated instances, in very heavy material, such as gravel, and where protected, as in those cases noted where the foundations surround and extend below the floor area, and in allied cases.

While the question of pressures on shafts presents some unusual conditions, in dry material it can probably be considered in the same way as, or rather in direct relation to, the pressures on grain-bins; *i. e.*, if one assumes that a grain-bin carries a centrally located pipe-shaft, one must conclude that the pressures on the shaft bear some direct relation to those on the bin itself, bearing in mind that the pressures are intensified by their convergence. Another element however comes in to offset the effect of some of this pressure, *i. e.*, the horizontal arching properties of the material; and it is not possible to determine this conclusively except by experiments on a large scale. In general, one may assume that the sides of small shafts up to five or six feet, in normally dry material, will not be subject to excessive or increased stresses due to increased depth, as the horizontal arching action of the material establishes a constant pressure beyond depths equal to four or five diameters of the shaft. The writer has supervised the sinking of numerous pits from four to six feet in diameter, for depths of from 20 to 45 feet, and has never seen in them any evidence of increased pressure due to depths. When the proportions of a shaft become greatly enlarged over the above figures, the pressures may be considered to be generally the same as those in trenches. In aqueous and semi-aqueous material over a percentage of the area the pressure of the water must be added to that of the solid material, as already noted.

The resistance of earth in its relation to the foundations of structures is a subject too broad to be considered herein. The questions relating to either piling or caissons, which are essential elements of foundations in aqueous or semi-aqueous materials, might, with difficulty, be encompassed in the limits of papers devoted exclusively to either. The writer wishes merely to emphasize the fact that in ordinary firm materials, such as sharp sand or gravel, or a mixture of both, we do not attach to the factors of resistance sufficiently high values. The fact is lost sight of that, when a reasonable depth of foundation is reached, the resisting power of firm material is increased, not so much because the material is more compact at great depths, but because the opportunity for lateral displacement is eliminated. A test has been made in which a 16-inch hollow pipe was cleaned

out to its bottom and a 14-inch piston placed therein, in which, at a depth of 77 feet below the curb, or 37 feet below ground-water, the piston supported 28 tons without further settlement, after an initial settlement of about 2¾ inches; while under a load of 15 tons the following observations were made, the material being ordinary sand:

Load.	Depth below Water.	No Further Settlement after the Initial of
15 tons per square foot	10 feet ±	¼ inch
15 " "	20 " ±	½ "
15 " "	37 " ±	0.37 "

While not conclusive, this test would tend to show that depth does not necessarily add to the stability of ground.

Tests have also been made on a 14-inch hollow pile in firm water bearing gravel, in which a measured circumferential area of 6½ square inches resisted a measured load of 60 tons, with no initial observed settlement.

Conclusions follow that any foundation on firm ground, deep enough to be guarded against and protected from lateral displacement, can be compacted by ramming or by driving short piles into it, or, if possible, by subjecting it to excess weight, to avoid the usual initial settlement due to compacting, and that it will then, without further settlement, resist pressure greatly in excess of that usually allowed.

Before concluding, the writer desires to note a few observations and reasons for his belief that the general principles outlined in this paper are true. In the first place, it is assumed that ground pressures are not subject to the same laws as aqueous pressures. If this were not true, it would be impossible to excavate deep trenches or tunnels, even in dry ground, without air-pressure. Not only is it possible to work safely at great depths in tunnels and trenches, but any one familiar with such work must realize that the bottom or floor of a deep tunnel or trench exposed for a large area shows no evidence of pressure in normally dry ground. The fact that pressure is not transmitted directly to the exposed bottom should be conclusive proof that arching action does exist in earth. It is also true that coffer-dams can be sunk to great depths in coarse sand or gravel adjacent to deep bodies of water by means of pumping, *i. e.*, without air-pressure, showing that the presence of water alone does not give aqueous properties to some materials. If, then, the arching action of normally dry earth exists to some degree,

as shown by the experiments, and in countless other instances, and if it exists to a large degree, as shown by the fact that deep excavations or tunnels can be safely made,—as safely as those at shallow depths,—why should we not accept it as a practical factor and not rather as an occasional freak of nature? The writer has never seen an instance in which the pressures in normally dry ground were greater than those accounted for in the body of this paper, and he can further give numerous observations showing conclusively that the pressures were not in excess of those allowed for herein in normally dry clays, loams, sands, gravel, or some mixtures of these. It will be necessary, however, to note but one or two here. The writer's attention has often been called to, and he has frequently examined, tunnels and large sewers in which the roof arches had cracked under pressure—one in particular, that of a cast-iron lined 15-foot tunnel, the roof plates of which were badly cracked after the passage of the shield. The writer believes that all these conditions—certainly those observed by him—can be explained by the fact that, on backfilling structures in trenches, or after the passage of the shield in tunnels, voids were left along the sides, and the normal subsidence of the ground above forced out the sides or haunches of the arch. The point of interest in all these cases is that the cracked arch sustained the ultimate loading, which had apparently been so great as to cause the initial rupture of the sound arch, and yet many engineers hold that the arching conditions may exist for a time, but eventually the full superimposed loading will come upon the structure. The writer holds that the arching properties are most effective when there is no further possibility of subsidence.

Another observation: The grade of the Joralemon Street approach to the Battery Tunnel was corrected above the water-line by cutting out sections of the bottom and lowering it from one to two feet, while in the roof 4 x 10 foot sections were cut out and jacked up 30 inches for long distances. The excavation of the bottom was accomplished by digging out, as in the ordinary trench work, after bracing the tunnel, while the roof plates were jacked up into the voids caused by displacing small quantities of sand around the exposed edges and through weep-holes. This work could not, of course, have been done had the full weight of the ground above, as is generally conceded, borne upon the full area of the roof of the tunnel.

As to deep trenches, the writer has often seen bracing crack near the top of a trench to such an extent that it had to be reinforced.

due to the fact that the trench was being deepened at that point. To use in a 30-foot sand trench bracing just strong enough at a point 15 feet down and not strengthen it on excavating the same trench to a depth of 60 feet would be suicidal, whereas at a point 10 feet above the bottom of a 60-foot trench bracing need not be any heavier than that 10 feet up from the bottom in a 30-foot trench, always assuming that the sand is normally dry. The danger of deep tunneling or trenching lies not in the normally dry, homogeneous materials, or even in firm ground when saturated, but it is rather due to the pockets of so-called quicksand, or "near quicksands," and to the treacherous soft clays, or those with well-defined seams of soft material along which they tend to slide in mass. In rare instances, even in rock, pressures may be found to be greater than in soft ground, where the stratification is vertical, or where pockets of disintegrated rock become detached from the solid mass around them. The writer desires, however, to impress upon the reader his belief that it is not depth which causes these conditions, necessarily, but that they are as likely to occur in tunnels at shallow depths as in those at very great depths; and to emphasize the original observation, that the greater the angle of repose in firm materials, the greater the pressure on a tunnel structure. Finally, the writer reiterates the plea that wherever possible the engineer will experiment on a large scale and note, wherever practicable, the results of observations, which may be of value. As he has already stated, to be of real value experiments must be made on full areas, and not on those which are a small proportion only of that affected.

Many of the experiments here noted are more fully described in the writer's paper, "Pressure, Resistance, and Stability of Earth," published in Volume lx of the "Transactions of the American Society of Civil Engineers," and much of the matter of this paper is transcribed therefrom in substance.

The writer desires to thank Mr. Frederick L. Cranford and Mr. James W. Nelson for valuable assistance and for apparatus for making the experiments noted.

Obituary

MELBOURNE E. DAVIS, Active Member,
Admitted February 17, 1900; died December 22, 1911.

C. H. OTT, Active Member,
Admitted January 12, 1884; died January 4, 1912.

CHARLES I. YOUNG, Active Member,
Admitted January 8, 1898; died January 6, 1912.

FRANCIS J. DRAKE, Associate Member,
Admitted December 21, 1907; died February 7, 1912.

The Engineers' Club of Philadelphia

1317 Spruce Street, Philadelphia, Pa.

Annual Report of the Board of Directors

FOR THE FISCAL YEAR 1911

January 27, 1912.

To the Members of the Engineers' Club of Philadelphia:

The Board of Directors herewith presents its report for the year ending December 31, 1911, as follows:

Eighteen stated and four special meetings of the Club were held, at which the maximum attendance was 300 and the average 101. Nine regular, two adjourned, and one special meeting of the Board of Directors were held.

The summary of membership on December 31, 1911, as compared with the summary of December 31, 1910, is as follows:

	1910			1911		
Class.	Resident.	Non-resident.	Total.	Resident.	Non-resident.	Total.
Honorary	2	2	4	2	2	4
Active	367	97	464	361	92	453
Associate	56	5	61	59	7	66
Junior	49	10	59	52	12	64
	474	114	588	474	113	587

Seventeen Active, eight Associate, and twenty-one Junior Members were elected; two Associate Members were transferred to the Active grade, four Juniors to the Active grade, and seven Juniors to the Associate grade; one Associate and five Active Members died; thirty-one Active, five Associate, and five Junior Members resigned; two Associate Members were dropped from the rolls, and two Active Members were reinstated to membership.

The record of deaths is:

J. Roosevelt Shanley, Active Member, died August 25, 1910.

Heber S. Thompson, Active Member, died March 9, 1911.

Francis Schumann, Active Member, died June 29, 1911.

Howard Wood, Active Member, died July 1, 1911.

James Christie, Active Member, died August 24, 1911.

Alexander G. Sparks, Associate Member, died October 24, 1911.

The following papers have been presented before the Club:

January 7.—"New York City's Additional Water Supply from the Catskill Mountains." Thomas H. Wiggin (Visitor).

January 13.—"Engineering Work of the Reclamation Service." F. H. Newell, Director of U. S. Reclamation Service.

January 21.—"The Functions of the Landscape Architect in Connection with the Improvement of a City." Thomas W. Sears (Visitor).

January 30.—"Esperanto: Its Benefit to the Engineer." Prof. A. M. Christen (Visitor).

February 4.—Annual Address—"The Beginning of Sanitary Science and the Development of Sewerage and Sewage Disposal." President William Easby, Jr.

February 15.—"The Engineering Features of the Panama Canal." Col. George W. Goethals (Visitor).

February 18.—"The Superstructure of the Passyunk Avenue Bridge." Henry H. Quimby (Active Member).

March 4.—"The Design of Impellers of Modern Centrifugal Pumps." N. W. Akimoff (Active Member). "Engineering Features of Electric Furnaces." Carl Hering (Active Member).

March 18.—"A Review of the Progress of City Planning." B. A. Haldeman (Active Member).

April 1.—"The Atlantic Coastal Project." J. Hampton Moore (Visitor).

April 15.—"The New York State Barge Canal." William B. Landreth (Visitor).

May 6.—"The Principles of Scientific Management." Frederick W. Taylor (Visitor).

May 20.—"The Forty-second Street Bridge in Philadelphia." Henry H. Quimby (Active Member).

June 3.—"The United States Fuel Testing Plant." S. B. Flagg (Visitor).

September 16.—"The Sanitary Supervision of the Catskill Aqueduct." Dr. David S. Flynn (Visitor), Sanitary Expert of the Catskill Aqueduct Commission.

October 7.—"Gas Production, with Special Reference to the Manufacture and Distribution of Illuminating Gas in Cities." C. J. Ramsburg (Visitor).

October 21.—"The Failure of the Austin Dam." John W. Ledoux (Active Member).

November 4.—"The Present Activities and Progress of the Coast and Geodetic Survey." Prof. O. H. Tittmann, Superintendent of the U. S. Coast and Geodetic Survey.

November 18.—"The Theory of Earth Pressures." J. C. Meem (Visitor).

December 2.—"Reclamation Engineering in Russian Turkestan." Arthur P. Davis (Visitor), Chief Engineer of the U. S. Reclamation Service.

December 16.—"The Water Power Plant of the City of Sturgis, Mich." Prof. Gardner S. Williams (Visitor).

Two social entertainments were held during the year. A reception and dance was held on April 24, 1911, the expenses of which were met by subscription, and a smoker on November 11, 1911, the expenses of which were defrayed from the Club funds. Both of these functions were well attended and successful in every way.

FINANCIAL REPORT.

Following is the report of the Treasurer upon the finances of the Club. It will be noted that the statement of Income and Expense for the year shows the very creditable gain of $2308.15. The Building Fund notes have been reduced from $9500.00 to $8100.00, and one $500.00 second mortgage bond has been retired and cancelled. The finances of the Club, therefore, are in excellent condition.

STATEMENT OF ASSETS AND LIABILITIES AS AT DECEMBER 31, 1911.

ASSETS.

Cash—Colonial Trust Co.—Active Account	$409.38	
Colonial Trust Co.—Interest Account	1,572.50	
In Office	213.70	
		$2,195.58
Accounts Receivable Members' Ledger		3,626.61

INVENTORY OF SUPPLIES ON HAND.

Wines and liquors	$262.51	
Cigars	195.57	
Fuel	18.20	
Restaurant provisions	103.19	
	$579.47	
Carried forward		$6,401.66

Brought forward		$6,401.66

PROPERTY.

Building No. 1317 Spruce Street	$72,850.00	
Furniture and fixtures—house	8,750.00	
Furniture and fixtures—restaurant	1,200.00	
Library	2,100.00	
		84,900.00

INSURANCE.

Perpetual on Club House	$1,782.00	
Unexpired on furniture	7.86	
		1,789.86

MISCELLANEOUS.

Bonds deposited by the Link Belt Company		1,000.00
Sinking fund for bond redemption		33.20
F. H. Stier, Treasurer		75.28
Total assets		$94,200.00

LIABILITIES.

Accounts payable		$2,978.53
Bills payable—building account		8,100.00
Bills payable		1,500.00
First mortgage	$40,000.00	
Second mortgage bonds	26,250.00	
		66,250.00
Accrued interest—first mortgage	$1,080.00	
Accrued interest—second mortgage bonds	1,572.50	
		2,652.50
Reserve for bond redemption		33.20
Link Belt Company Fund		704.58
Reserve for redemption of Link Belt bonds		295.42
Appropriation from Junior Section to Library Committee		203.49

CHRISTMAS FUND.

Balance, January 1, 1911	$33.00	
Contributions, December, 1911	277.00	
	$310.00	
Disbursements, December, 1911	250.00	
		60.00
Total liabilities		$82,777.72

Brought forward		$82,777.72

SURPLUS.

Surplus as at January 1, 1911	$7,989.13	
Transfer of initiation fees from bond reserve	625.00	
Cancellation of second mortgage bond	500.00	
Gain for year 1911 as per statement of income and expense	2,308.15	
Surplus as at December 31, 1911		$11,422.28
		$94,200.00

STATEMENT OF INCOME AND EXPENSE, YEAR ENDING DECEMBER 31, 1911.

INCOME.

Dues—net		$16,526.96	
Publications:			
Advertising directory	$520.00		
Advertising Proceedings	588.40		
Sales Proceedings	44.71		
Total from publications		1,153.11	
Miscellaneous:			
Interest on deposits	$18.37		
Badge sales	6.00		
Initiation fees	780.00		
Reprints	34.00		
Miscellaneous income	5.70		
Total miscellaneous income		844.07	
Club House Business:			
Restaurant sales	$7,222.28		
Wine sales	1,185.26		
Cigar sales	1,596.52		
Billiards and pool	191.55		
Lodging	3,063.58		
Rent of meeting-room	137.50		
Total income from Club House business		13,396.69	
Total income, year ending December 31, 1911			$31,920.83

EXPENSES.

Salaries and Wages:		
House salaries and wages	$2,922.96	
Office salaries	2,409.39	
Restaurant salaries and wages	3,815.51	
Total salaries and wages		$9,147.86

Brought forward		$9,147.86
EXPENSE:		
House expense	$1,279.79	
Office expense	388.52	
Total expense		1,668.31
PUBLICATIONS:		
Directory publishing	$291.24	
Proceedings publishing	1,148.86	
Reprints	28.85	
Total from publications		1,468.95
MISCELLANEOUS:		
Gas and electric light	$921.56	
Telephone	156.05	
Badge purchases	4.00	
Club luncheons	348.00	
Entertainment Committee	230.95	
Fuel	384.25	
Insurance	51.00	
Meetings Committee	503.68	
Membership Committee	101.50	
Taxes and water rent	943.00	
State tax on bonds	103.00	
Trustees of Bond Redemption Fund	3.00	
Suspense	49.59	
Total miscellaneous expense		3,799.58
INTEREST AND DISCOUNT:		
Interest on first mortgage	$2,160.00	
Interest on second mortgage bonds	1,255.89	
Interest on Building Fund notes	363.68	
Discount on notes	7.75	
Total interest and discount		3,787.32
CLUB HOUSE BUSINESS:		
Restaurant purchases	$6,622.02	
Restaurant supplies	195.81	
Restaurant ice	192.88	
Restaurant laundry	216.01	
Restaurant renewals	12.97	
Restaurant equipment	156.21	
Cigar purchases	1,432.88	
Wine purchases	853.73	
Billiards and pool	35.10	
Total expense of Club House business		9,717.61
Carried forward		$29,589.63

Brought forward				$29,589.63
INVENTORY, DECEMBER 31, 1911.				
Wines	$262.51			
Cigars	195.57			
Fuel	18.20			
Restaurant provisions	103.19			
		$579.47		
INVENTORY, DECEMBER 31, 1910.				
Wines	$251.23			
Cigars	65.00			
Fuel	66.00			
Restaurant provisions	89.14			
		471.37		
Deduct increase in inventory			108.10	
Total Club House business exclusive of salaries and wages			$9,609.51	
DEPRECIATION:				
Furniture and fixtures—house		$41.40		
Furniture and fixtures—restaurant		29.59		
Library		.59		
Property		59.57		
Total depreciation			131.15	
Total expense, year ending December 31, 1911				$29.612.68
Net gain, year ending December 31, 1911				2,308.15
				$31,920.83

Respectfully submitted,

F. H. Stier,
Treasurer.

Audited and found correct.

Stockton Bates, C. P. A.,
For Stockton Bates and Sons.

We have examined this statement, prepared by the certified accountants, and believe it to be correct.

W. B. Riegner,
D. Robert Yarnall,
Auditors.

The following is the report of the Trustees of the Bond Redemption Fund:

Fourth Annual Report of the Bond Redemption Fund.

Being a Statement of Business for the Year 1911.

RECEIPTS.

Balance January 1, 1911	$403.39	
1–31 Initiation fees	105.00	
1–31 Repayment of expenses	4.50	
6–30 Interest on deposit	1.43	
		$514.32

EXPENDITURES.

2–10 Bond No. 205, at 95 per cent.	$475.00	
2–10 Accrued interest to 2–15–11	3.12	
6–19 Box rent	3.00	
		481.12
Balance		$33.20

Bond No. 205, par value $500.00, was purchased on February 10, in accordance with the rules, for 95 per cent. and accrued interest to that date. The bond and unmatured coupons were cancelled and delivered to the trust office of the Colonial Trust Company.

The Trustees hold no negotiable securities.

Henry Leffmann,
Edwin F. Smith,
Edgar Marburg,
Trustees.

We have examined the above account and believe it to be correct. The bank balance is of November 1, 1911, and is correct.

W. B. Riegner,
D. Robert Yarnall,
Auditors.

Respectfully submitted,
The Board of Directors,
Henry Hess,
President.
W. P. Taylor,
Secretary.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, January 6, 1912.—The meeting was called to order by President Hess at 8.40 p. m., with about 65 members and visitors in attendance. The minutes of the special meeting of December 9th and the business meeting of December 16th were approved as printed in abstract.

The following motion was presented by Mr. Robert Schmitz and carried: "That the Secretary be instructed to send a copy of the resolutions passed by the Club at the meeting of December 9, 1911, to each of the other engineering societies and clubs within the State, with the request that they take similar action."

Following a report of the tellers, the President declared the following elected to membership: Active, Charles Chapman Anthony, George LaRue Thompson; Associate, Leroy Moody Lewis.

Captain C. W. Dyson, U.S.N., presented the paper of the evening, entitled "Propulsive Machinery and Oil Fuel in the U. S. Naval Service," which was discussed by Rear Admiral George W. Melville, U.S.N., Honorary Member of the Club, whose discussion was presented by Rear Admiral John R. Edwards, Inspector of Machinery in the U. S. Naval Service; Mr. Charles Gordon Curtiss; Mr. H. T. Herr, of the Westinghouse Co.; Mr. Lovell, Chief Engineer of the Fore River Ship and Engine Co.; Capt. Bryan, of the U. S. Naval Service at League Island Navy Yard; Mr. Charles Hewitt, Mr. E. J. Dauner, and others.

On motion of Mr. Hewitt a vote of thanks was extended to Captain Dyson and all who participated in the presentation and discussion of the paper.

On motion of Mr. Trautwine a unanimous vote of thanks was extended to President Hess for the magnificent lantern which he presented the Club as a Christmas gift, and which was used for the first time at this meeting.

Regular Meeting, January 20, 1912.—The meeting was called to order by Vice-President Hewitt at 8.30 p. m., with 122 members and visitors in attendance. The minutes of the business meeting of January 6th were approved as printed in abstract.

Two resolutions were read in abstract, and it was announced that they would be brought up for discussion at the following regular meeting of the Club.

Mr. Henry Japp, visitor, presented the paper of the evening, entitled, "Subaqueous Tunneling," which was discussed by Messrs. H. H. Quimby, S. M. Swaab, John C. Trautwine, Jr., and others. On motion of Mr. Swaab a vote of thanks was extended to Mr. Japp.

Special Meeting, January 27, 1912.—The meeting was called to order by President Hess at 8.30 p. m., with 75 members and visitors in attendance.

Mr. W. J. Barney, Deputy Commissioner, Department of Docks, New York

City, presented the paper of the evening, entitled, "Dock Facilities in New York City; Present Facilities, Proposed Improvements and Extensions." The discussion was opened by Director Norris, of the Department of Docks, and was participated in by Colonel Sanford, U.S.A., Mr. John C. Trautwine, Jr., and Mr. Henry Hess, and was closed by Mr. Barney.

A vote of thanks was moved by Mr. Plack and seconded by Mr. Hutchinson.

Thirty-third Annual Meeting, February 3, 1912.—The meeting was called to order by President Hess at 8.35 p. m., with 67 members and visitors in attendance. The minutes of the regular meeting of January 20th were approved as printed in abstract.

The Annual Report of the Board of Directors was presented and approved.

Following a report of the tellers, the following were declared elected to membership: Active, H. Gordon Hinkle; Associate, Charles F. Morrall; Junior, Charles W. G. Haydock, Robert A. Hentz, and William H. T. Thornhill.

President Hess, after relinquishing the chair to Vice-President Plack, delivered the Annual Address.

Following this address Mr. Frederick E. Ives, with Mr. Hess, gave a talk and demonstration of recent developments in color measurement and color photography, which was discussed by several of the members. On motion of Mr. Snook a vote of thanks was tendered to Messrs. Ives and Hess.

The discussion of the two resolutions scheduled to be brought up for discussion at this meeting was, on account of the lateness of the hour, postponed until the following meeting of the Club.

Following the report of the tellers of election the following were elected as officers of the Club for 1912:

President: Henry Hess.
Vice-President: Charles F. Mebus.
Secretary: W. Purves Taylor.
Treasurer: F. H. Stier.
Directors: H. C. Berry, B. A. Haldeman, S. M. Swaab, D. Robert Yarnall.

Special Meeting, February 10, 1912.—The meeting was called to order by Vice-President Plack at 8.30 p. m., with 58 members and visitors in attendance. Mr. Howard W. DuBois presented the paper of the evening, entitled, "Hydraulic Gold Mining in British Columbia."

Regular Meeting, February 17, 1912.—The meeting was called to order by President Hess at 8.25 p. m., with 65 members and visitors in attendance.

A resolution from the Engineers' Club of St. Louis, calling attention to defects in the existing patent laws, and resolving a recommendation that remedial legislation be enacted, was read, discussed, and referred to a special committee of the Board, to report at the regular meeting of the Club on March 16th.

A resolution from the Philadelphia Chapter of the American Institute of Architects, calling attention to the impropriety of the erection of a national highway as a memorial to Abraham Lincoln, resolving that a more suitable form

of memorial be adopted, was read, discussed, and, upon motion, unanimously indorsed.

Mr. H. Clyde Snook presented the paper of the evening, entitled, "The Development of Roentgenology," which was discussed by a number of members and visitors. Upon motion of Mr. Swaab a vote of thanks was extended to Mr. Snook.

Business Meeting, March 2, 1912.—The meeting was called to order by President Hess at 8.35 p. m., with 62 members and visitors in attendance. The minutes of the special meeting of February 10th, and the regular meeting of February 17th, were approved as printed in abstract.

Following a report of the tellers, the following were declared elected to membership: Active, William Likens Brown, Claude B. Hagy, William Tudor Price; Junior, Thomas M. Chance, Clarence W. Rodman.

Mr. Warren, of the Iszard-Warren Company, presented a short paper descriptive of certain new features in surveyors' instruments made by that company.

Lieutenant Colonel Odus C. Horney, U.S.A., presented the paper of the evening, entitled, "Smokeless Powder and High Explosives for Military Uses," which was discussed by Messrs. Robert Schmitz, E. M. Nichols, W. P. Taylor, Henry Hess, H. M. Chance, Martin Nixon-Miller, and others. On motion of Dr. Chance a vote of thanks was extended to Colonel Horney.

Business Meeting, March 16, 1912.—The meeting was called to order by Vice-President Hewitt at 8.20 p. m., with 99 members and visitors in attendance. The minutes of the business meeting of March 2d were approved as printed in abstract. Mr. H. H. Quimby, Chairman of the Committee on Public Relations, presented the following resolution, which was unanimously adopted:

"*Resolved*, that it is the sense of this Club that the patent laws of the United States are in need of revision, in order to safeguard more completely and equitably the interests of both inventors and the public, and that to this end the President of the United States should be authorized by Congress to appoint a commission of competent persons to make a study of the subject and suggest such legislation as may appear to be wise and efficacious."

It was further moved and carried that the Secretary be instructed to transmit a copy of this resolution to Congress.

Mr. B. A. Haldeman, Chairman of a special committee appointed to represent the Club at a conference in the Mayor's office on "The Promotion of the Systematic Planting and Care of Shade Trees in the City," moved the adoption of the following resolution, which also was carried:

"*Resolved*, that the Engineers' Club of Philadelphia recommend that the sum of $50,000 be appropriated by Councils to the Commissioners of Fairmount Park, acting as the Shade Tree Commission of this city, to be used in encouraging and assisting the planting of shade trees in the streets of the city, and in maintaining such trees as now exist or may hereafter be planted."

Dr. John A. Brashear, of Pittsburgh, Pa., presented the paper of the evening, entitled, "Stellar Evolution," which was followed by short addresses by Professor Charles L. Doolittle and Professor M. B. Snyder. On motion of Mr. John C. Trautwine, Jr., the thanks of the Club were extended to Dr. Brashear for his extremely interesting and instructive paper.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS

Regular Meeting, January 18, 1912.—Present: Vice-President Hewitt, Directors Mebus, Halstead, Kerrick, Worley, Cooke, Develin, Gilpin, Haldeman, the Secretary, and the Treasurer.

The question of auditing the Club accounts was brought up for discussion, and the two Club Auditors present stated that the informal audit they gave the Club books was neither fair to themselves nor to the Club. After discussion, it was agreed that the Auditors certify to the report for the current year, but that the Board of Directors propose an amendment to the By-Laws of the Club to the effect that a certified public accountant be employed for the annual audit.

The Treasurer presented his annual report of the finances of the Club, which was accepted and ordered to be printed.

The report of the Trustees of the Bond Redemption Fund was also read, accepted, and ordered printed.

It was ordered that the Committee on Delinquent Accounts be given power to act in the matter of collections.

The Chairman of the Finance Committee presented a report, recommending that the building-fund notes be retired in a manner exactly similar to that employed for the second-mortgage bonds. This report was approved.

The House Committee presented a report, which was ordered to be filed, and the matters therein referred to the House Committee to be appointed next year.

It was moved that a vote of thanks be extended to the Chairman of the Meetings Committee for his success in securing an exceptionally high standard of papers during the past year. It was also moved that a vote of thanks be extended to the Chairmen of the House and Publication Committees for their services to the Club.

Messrs. Thomas H. Griest and D. L. Britten were, upon request, transferred from Associate to Active membership.

The following resignations were read and accepted: Jerome W. Howe, Wm. F. Newbery, G. M. Sinclair, F. M. Cresson, Gordon Brandes, Lionel F. Levy, H. M. Geer, W. L. Haynes, Benjamin Franklin, and J. F. Hasskarl.

Messrs. J. W. Campbell and H. T. McGaughan were transferred from resident to non-resident membership, provided that a mailing address outside the thirty-mile limit of Philadelphia be given.

Letters from the Engineers' Club of St. Louis, asking for resolutions relative to patent laws, and a letter from the Philadelphia Chapter of the American Institute of Architects, recommending resolutions on the Lincoln Memorial, were read, and ordered to be brought before the next meeting of the Club.

A report of the special committee on ventilating the meeting room was read and ordered to be filed.

The following resolution was passed:

Resolved, that the thanks of the Board be presented to President Hess for the gift of a projecting lantern and microscope; and

Resolved, that a plate be purchased, setting forth the date of the donation and the name of the donor, and applied to the lantern.

ORGANIZATION MEETING, February 15, 1912.—Present: President Hess, Vice-Presidents Hewitt, Plack, Mebus, Directors Halstead, Cooke, Develin, Vogleson, Berry, Haldeman, Swaab, Yarnall, and the Secretary.

It was moved and carried that the second part of the resolution passed January 18th, resolving that a plate be affixed to the lantern, be rescinded.

The following resignations were read and accepted: L. H. Losse, H. E. Snyder, Thomas F. Smith, Wyllys E. Dowd, Jr., Thomas H. Griest, Sydney B. Strouse, St. John Chilton, Charles F. Thacher, Jr.

The deaths of Francis J. Drake and Charles I. Young were announced.

A letter from the Treasurer, relative to members delinquent in dues, was read and laid on the table until the following meeting of the Board. A report of the Committee on Delinquent Accounts was presented, the report adopted, and the Committee discharged with thanks.

The Secretary was instructed to put into immediate effect the recommendations of the Committee.

The following were appointed standing Committees for the coming year, the Chairman of each Committee to appoint one or two additional members from the membership at large to serve as associate members of the Committee:

House: F. K. Worley, W. L. Plack.
Meetings: S. M. Swaab, H. C. Berry.
Membership: Charles Hewitt, F. H. Stier.
Finance: J. A. Vogleson, David Halstead.
Publication: Charles F. Mebus, St. George H. Cooke.
Library: B. A. Haldeman, Richard Gilpin.
Publicity: R. G. Develin, E. J. Kerrick.
Advertising: D. Robert Yarnall, Percy H. Wilson.

The following were then elected by the Board to serve as Tellers and Auditors:

Tellers: E. J. Dauner, L. H. Kenney, G. Wise.
Alternate Tellers: C. A. Bockius, A. D. Morris, Charles Elcock.
Auditors: W. B. Riegner, J. H. M. Andrews.

The following were appointed a Committee to revise the rules governing the Board of Directors, and to report at the next meeting of the Board: Charles F. Mebus, S. M. Swaab, W. P. Taylor.

On motion the President was authorized to appoint a Committee of eleven on "Public Relations," this Committee to be authorized temporarily to increase its membership for specific purposes, six of the eleven members to be appointed from the membership of the Board. The following were then appointed members of this Committee: H. H. Quimby, Edgar Marburg, Henry Leffmann, John C. Trautwine, Jr., Edwin F. Smith, Charles Hewitt, W. L. Plack, Charles F. Mebus, S. M. Swaab, Henry Hess (ex officio), W. P. Taylor (ex officio).

The following were appointed a Committee to prepare and present to the Board at its next meeting suggested amendments to the By-Laws of the Club: Charles Hewitt, J. A. Vogleson, W. L. Plack.

It was moved and carried that a Committee of five be appointed to investigate the conditions of this Club, and similar organizations in other cities, and gather all possible information about the management of such organizations, and report at the regular meeting of the Board in May. Mr. Mebus was appointed Chairman of this Committee, the other members to be appointed by him.

The Committee on Increase of Membership and the Art Committee were continued.

The House Committee was authorized to sell the old lantern.

Regular Meeting, March 14, 1912.—Present: Vice-Presidents Hewitt and Plack, Directors Worley, Cooke, Gilpin, Vogleson, Swaab, Yarnall, and the Secretary.

The Secretary announced that the Auditors, the Tellers of Election, and the Alternate Tellers, with the exception of Mr. C. A. Bockius, had accepted appointment to these offices.

It was also announced that the Committee to investigate Club Organization was appointed by Mr. Mebus as follows: Charles F. Mebus, S. M. Swaab, F. K. Worley, D. Robert Yarnall, and W. P. Taylor.

The Secretary presented a report, showing the condition of the finances, and showing a net gain of $68.00 in the income and expense account for the first two months of 1912.

The death of Melbourne E. Davis was announced.

The resignation of J. A. Wolle was read and accepted.

The Chairman of the Membership Committee reported that W. P. Dallett and Robert T. Mickle had been appointed associate members of this Committee.

Richard Gilpin, Chairman of the Library Committee, presented a report relative to the indexing of the library, which was referred back to the Committee for further report at the next meeting.

In connection with the work of the House Committee, correspondence from Mr. Carl Hering and Dr. Owens, relative to spigots in the bath-rooms, was read and referred back to the House Committee for action.

A letter from Mr. Hess, relative to an appliance for ventilating the meeting-room, was read and referred to a special committee on this subject.

The special Committee appointed to represent the Club at a conference in the Mayor's office on the planting and care of shade trees in the city read its report, which was received. A resolution contained in this report was ordered to be read at the next meeting of the Club. The Committee was then discharged with thanks.

The report of the special committee appointed to revise the rules for the government of the Board of Directors was read and adopted, subject to a few changes in phraseology.

THE ENGINEERS' CLUB OF PHILADELPHIA

1317 Spruce Street

OFFICERS FOR 1912

President
HENRY HESS

Vice-Presidents

Term Expires 1913
CHARLES HEWITT

Term Expires 1914
W. L. PLACK

Term Expires 1915
CHARLES F. MEBUS

Secretary
W. P. TAYLOR

Treasurer
F. H. STIER

Directors

Term Expires 1913	*Term Expires 1914*	*Term Expires 1915*
DAVID HALSTEAD	ST. GEORGE H. COOKE	H. C. BERRY
E. J. KERRICK	R. G. DEVELIN	B. A. HALDEMAN
PERCY H. WILSON	RICHARD GILPIN	S. M. SWAAB
F. K. WORLEY	J. A. VOGLESON	D. ROBERT YARNALL

STANDING COMMITTEES OF BOARD OF DIRECTORS

House—F. K. Worley, W. L. Plack.
Meetings—S. M. Swaab, H. C. Berry.
Membership—Chas. Hewitt, F. H. Stier.
Finance—J. A. Vogleson, David Halstead.
Publication—Chas. F. Mebus, St. George H. Cooke.
Library—B. A. Haldeman, Richard Gilpin.
Publicity—R. G. Develin, E. J. Kerrick.
Advertising—D. Robert Yarnall, Percy H. Wilson.

MEETINGS

Annual Meeting—1st Saturday of February, at 8.15 p. m.

Stated Meetings—1st and 3d Saturdays of each month, at 8.15 p. m., except between the fourteenth days of June and September.

Business Meetings—When required by the By-Laws, when ordered by the President or Board of Directors, or on the written request of twenty-five Voting Members of the Club.

The Board of Directors meets on or before the 3d Saturday of each month, except June, July and August.

PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

Vol. XXIX. JULY, 1912. No. 3

PAPER NO. 1109.

SUBAQUEOUS TUNNELING.*

HENRY JAPP
(Visitor.)

Read January 20, 1912.

SUBAQUEOUS tunneling has always presented special difficulties to the financier, the engineer, and the contractor, and is generally postponed or avoided—like the doctor, whose acquaintance is not sought unless absolutely necessary. Where good foundations are available and the spans are not too great, bridging is the most suitable method of getting over waterways overhead if the approaches are feasible, or by low level with a drawbridge if the water traffic is not too great. Ferry-boats have been and are now used, and will be for many years, until the delays and interruptions of a great traffic represent a sufficient money loss to capitalize bridges or tunnels where bridges are impracticable.

In the early part of 1904, when the writer made his first acquaintance with New York city, there was no river subaqueous traveling. There are now 16 tubes, viz., 2 for the Rapid Transit under the Harlem

* By courtesy of the American Society of Civil Engineers a number of diagrams are reproduced in this paper from papers by the writer, and published by the American Society of Civil Engineers, as follows: "Caisson Disease and Its Prevention," Transactions, vol. lxv, p. 1; and "Contractor's Plant for the East River Tunnels," vol. lxix, p. 1.

River, and 2 under the East River at the Battery; for the Pennsylvania Railroad there are 4—2 main line and 2 suburban tubes; and 2 Belmont Tunnels, all under the East River. Under the North River there are 4 Hudson and Manhattan tubes and 2 Pennsylvania tubes at Thirty-third Street.

The population since 1904 has increased from 3,500,000 to 5,000,000, and in addition to the 16 tubes, 3 additional bridges have been built over the East River, so that if the one Brooklyn Bridge was sufficient to take care of 3,500,000 people, certainly 16 tunnels and 4 bridges must be more than enough now. The Belmont tunnel is not used at all, and that represents $8,000,000 capital which is tied up while the city makes up its mind to whom it belongs, and at least two of the new bridges are used very little.

Generally speaking, it is inadvisable and practically impossible to tunnel under water in other than solid rock or stiff clay without the aid of air-pressure.

The Thames tunnel was the first tunnel built with a shield as far back as 1818, by that great genius, Brunel. The length of this tunnel was 1200 feet, and it took twelve years to drive it. It was built of brickwork, with two arched openings each wide enough for a main-line track. The face of the shield was divided into horizontal strips of timber or breast boards, supported on a wooden frame and pushed forward by screw-jacks. The polling boards for the roof and sides were also supported by the framing, and moved forward by screw-jacks, the polling boards tailing back over the finished brickwork like the tail of a modern shield.

At the time same Mr. Brunel took out a patent for a tunnel driven by a circular shield moved forward by jacks, with a cast-iron lining. In this respect Mr. Brunel was a man very far ahead of his time. The timber shield was pushed through under the river without any air-pressure, although the material was gravel, and on one occasion the water and gravel burst into the tunnel, removing the overlying material and damaging the shield. Mr. Brunel went down in a diving-bell on top of the shield and repaired it himself. After dumping clay over the cavity in the river-bed he pumped out the tunnel and struggled along for twelve years.

Lord Cochrane, in 1830, took out the first patent for driving a tunnel by means of compressed air, and his patent was so complete and perfect that it foreshadowed many of the ideas that have since been adopted.

Barlow and Greathead built the first shield-driven cast-iron-lined tunnel in 1868 under the Thames; it was about 6 feet in diameter through hard clay, and required no air-pressure. One end of it is situated near the Tower of London, and was used for foot-passengers. As a sample of what could be done with a shield-driven tunnel it was very successful. Two years later Mr. Beach, in New York, followed with a brick-lined tunnel, using hydraulic jacks for the first time. His short length of tunnel under Broadway is now being removed to make room for the new subway.

In the Hudson Tunnel, in 1879, Mr. Haskins used compressed air for tunnel driving for the first time. He was under a misapprehension that compressed air would hold the Hudson silt up like a soap-bubble, but, of course, it did not, and being compelled to put in a sheet-iron lining, he developed for the first time the feasibility of tunneling in this way.

In the same tunnel Anderson developed the pilot system of tunneling by driving a small, sheet-iron-lined tunnel, about 6 feet in diameter, in the center of the main one. He propped the steel lining of the main tunnel radially from the pilot lining. This method was very successful, and 2000 feet was driven by this means, but when well under the river the silt was so soft that it caved in and drowned a lot of men, and the enterprise was stopped.

It was then taken up by some English capitalists, and Sir Benjamin Baker was sent out to investigate conditions. After inspecting the tunnel he found he could not lock himself out again; no matter how wide he opened the exhaust valve of the air-lock, the air-pressure leaked in around the door faster than the valve would let it out; he was in danger of being kept in there indefinitely, and it was only after smearing the door with Hudson silt that he got out. On his advice a contract was let to S. Pearson & Son, Limited, and a shield was designed under the auspices of Sir Benjamin Baker and built at the Forth Bridge Works, in Scotland, and shipped out here and built under the Hudson.

It was necessary to mine out a shield-chamber, and in doing this the silt came in and filled the tunnel, leaving a conical cavity from the tunnel up to the bed of the river. The more the silt was excavated from the tunnel, the more it ran in from the river, and it was not until the cavity was closed by means of a canvas balloon filled with clay and manure, lowered down by a Meritt Chapman derrick, that the flow stopped. The lock-doors were then jacked open, and the silt

allowed to flow until the men got back into the tunnel. The shield was then transported in small pieces and built down below, 2000 feet from the river bank. It was built under a pressure of 35 pounds per square inch, the rivets being heated in a forge with a funnel 2000 feet long, and one can imagine the intense heat with a draft of 35 pounds of air. The men working under these conditions, with the fumes from the forge, were very subject to caisson-disease, and 25 per cent. of them died. This was not checked until Mr. Moir, who was in charge, and is now regarded as a pioneer of shield-driven subaqueous tunneling, built the first medical air-lock that was ever made, and reduced the death-rate to 1 per cent.

In 1892 the Baring Bank in London failed, and the Company financing the work went bankrupt. All that the contractors got out of it was a mechanic's lien on the plant. When they stopped work on this tunnel they were making 10 feet of finished tunnel per day, and showed the way for all future work under the Hudson.

About the same time Mr. Hobson, of the Grand Trunk Railway, was driving a tunnel from Canada to the United States, under the St. Clair River, where a speed of 8 feet per day was made. Two shields were used, which met in the middle of the river. This was the first compressed-air, shield-driven, cast-iron tunnel in the United States and Canada, and is still in operation, having recently been electrified.

The next tunnel of importance is the Blackwall Tunnel, which is the first completed subaqueous compressed-air, shield-driven tunnel let as a contract. S. Pearson & Son, Limited, the contractors, were told they could never accomplish it, but it was successfully completed at the contract price. It is 27 feet in diameter, and the difference in pressure between the top and bottom of the tunnel was nearly 12 pounds. It was found that if the pressure was kept high enough to drive the water out of the bottom, then the roof was blown off, and if the pressure was reduced the bottom came in, so a compromise had to be made, and a clay blanket was dumped in the river-bed so as to permit the pressure to be raised to about half-way down the shield. It was a difficult piece of work, and for part of the way the gravel had to be clawed out by means of the fingers through small openings in the shutters, which were advanced to the face of the cutting-edge, and as the shield was pushed ahead the shutters were allowed to slide back on frictions. The total subaqueous distance was 1200 feet, and it required twelve months, or 12 times the speed

of the Thames Tunnel for the same distance. Mr. Moir was in charge of this work also.

Mr. McAdoo and Mr. Jacobs, about 1903, took up the question of continuing the Hudson Tunnel and got sufficient capital together to build it. They found the old shield in good condition, and pushed it through eventually, and thus finished the first subaqueous passenger tunnel in New York.

Mr. Jacobs found great difficulty in mining the silt top with a rock bottom, and he devised an apron extending in front of the shield to hold up the silt while the men drilled the rock. Since then Mr. Jacobs has done some very fine work for the Hudson Manhattan companies, and attained very great speeds in the Hudson silt.

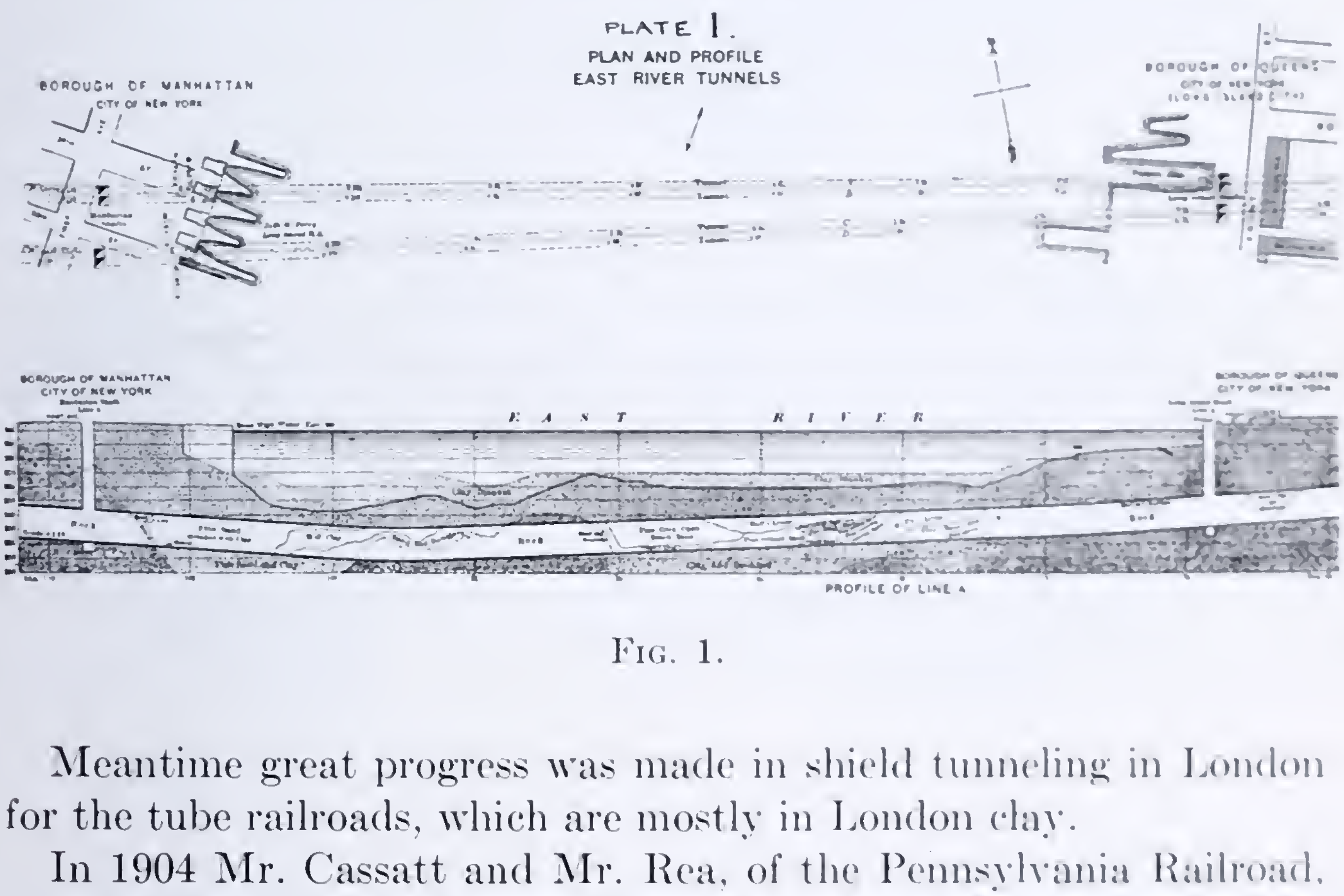


FIG. 1.

Meantime great progress was made in shield tunneling in London for the tube railroads, which are mostly in London clay.

In 1904 Mr. Cassatt and Mr. Rea, of the Pennsylvania Railroad, contracted for the tunnels under the Hudson and East Rivers for the great New York Terminal. The contract for the East River was awarded to S. Pearson & Son, Inc., and, as the writer had charge of this work for the contractors, a brief description of this work will be more fitting than following other work with which the writer is not intimately acquainted.

Fig. 1 shows the general plan and profile of the four tubes under the East River, New York. The Long Island service consists of two tubes under the East River, and connects the Terminal Station to the Long Island Railroad at the Sunnyside Yard. The Pennsylvania

trains are taken through by electric locomotives under the North River from Harrison, N. J., and after discharging the passengers at the terminal, the trains pass on under the East River to the Sunnyside Yard, where the cars are marshaled and cleaned and revictualed ready for going out on the west-bound tracks. The electric locomotives are 4000 H.P. each, and go as far as Harrison, where they are changed for steam locomotives.

There are four tunnels under the East River, and this plate shows the subaqueous portion from the Manhattan shafts to the Long Island

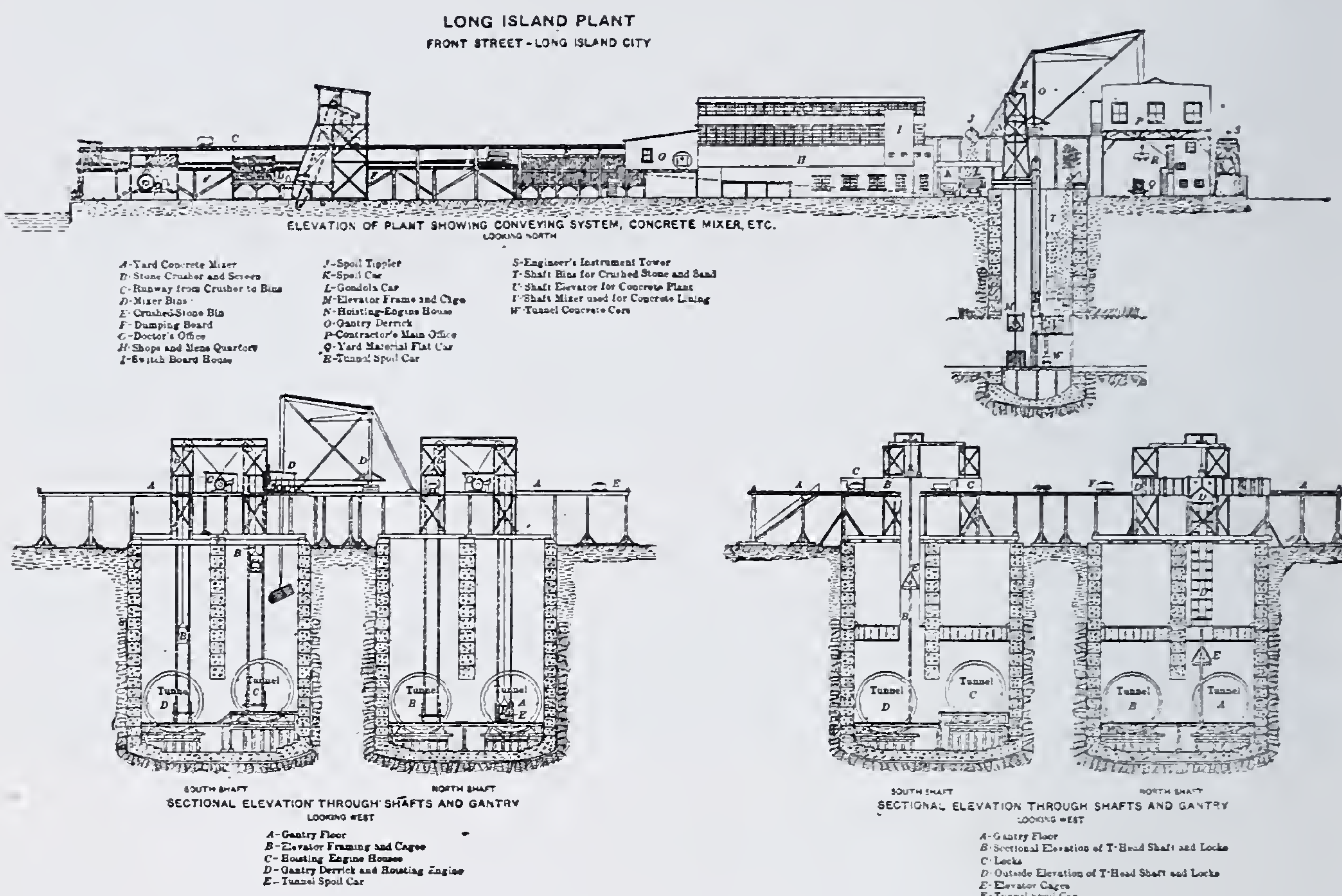


FIG. 2.

shafts, a total of about 24,000 feet of cast-iron-lined tunnel; each tunnel extended 2000 feet inland to the East Avenue shaft in Long Island city. This shows the water-line and the bed of the river; also the line of the rock. Generally speaking, the tunnel went through one-third of solid rock, one-third mixed rock and sand, and one-third of quicksand.

The work lent itself very favorably for management; it was divided into three working sites, comprising 8000 feet of tunnels at each. From Manhattan four tubes of 2000 feet each were driven eastward under the river; from Long Island, four tubes 2000 feet each westward under the river, and at East Avenue four tubes of 2000 feet

east westward under the land to the Long Island shafts. At East Avenue one shaft was sunk in the rock without air-pressure large enough to take in the four tunnels. The excavations were dumped on Long Island Railroad cars and used for embankment purposes.

Fig. 2 shows the lay-out of the plant for the Long Island city site.

Fig. 3 shows the power-house at Manhattan—that at Long Island was very similar. This plate shows a cross-section of the power-house showing the air-compressors and receivers. Each compressor was arranged so that by a four-way manifold it could discharge the air into any or all the tunnels, or all the compressors could be turned into one tunnel. This arrangement was very flexible, inasmuch as it

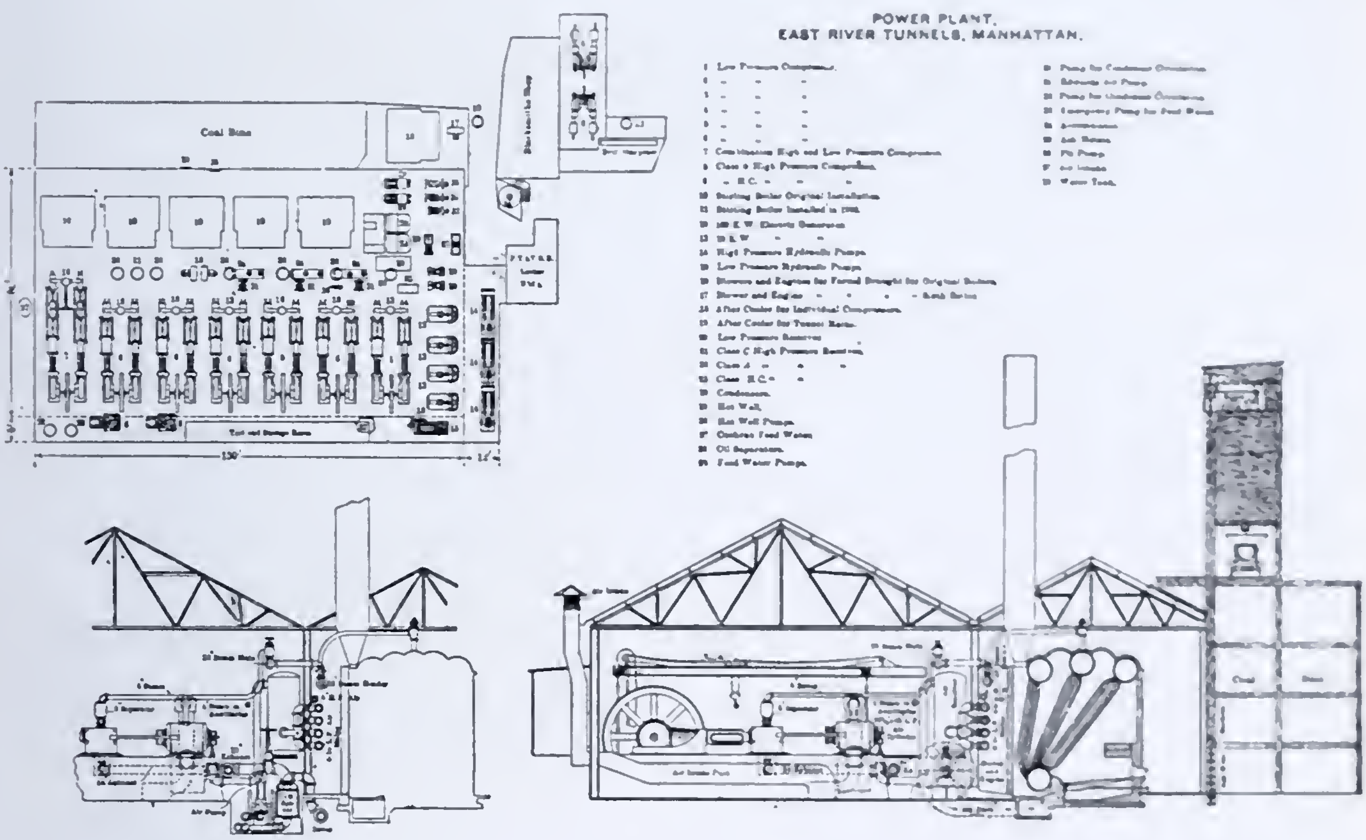


FIG. 3.

took care of every conceivable combination. At Manhattan there were seven steam-driven air-compressors of 6250 cubic feet capacity each, and at Long Island there were two additional compressors, electrically driven, as well as seven steam-driven compressors similar to those at Manhattan.

Fig. 4 is a photograph showing the air-compressors in the Manhattan power-house—that is, some of them, as all of them could not be put into one photograph. The combined capacity of the two plants was 100,000 cubic feet of air per minute. This can be grasped more readily if one considers a pipe-line 20 miles long with a cross-sectional

area of one square foot, and if all the compressors discharged the air at this rate into this pipe simultaneously the air could reach the other end in one minute. The compressors were built by Ingersoll Rand, and were very efficient and dependable.

To supply hydraulic pressure for shoving the shields and for erecting the iron lining three hydraulic pumps were provided on each side of the river, all capable of compressing up to 6000 pounds per square inch to push the shields. But one on each site was used for a pressure

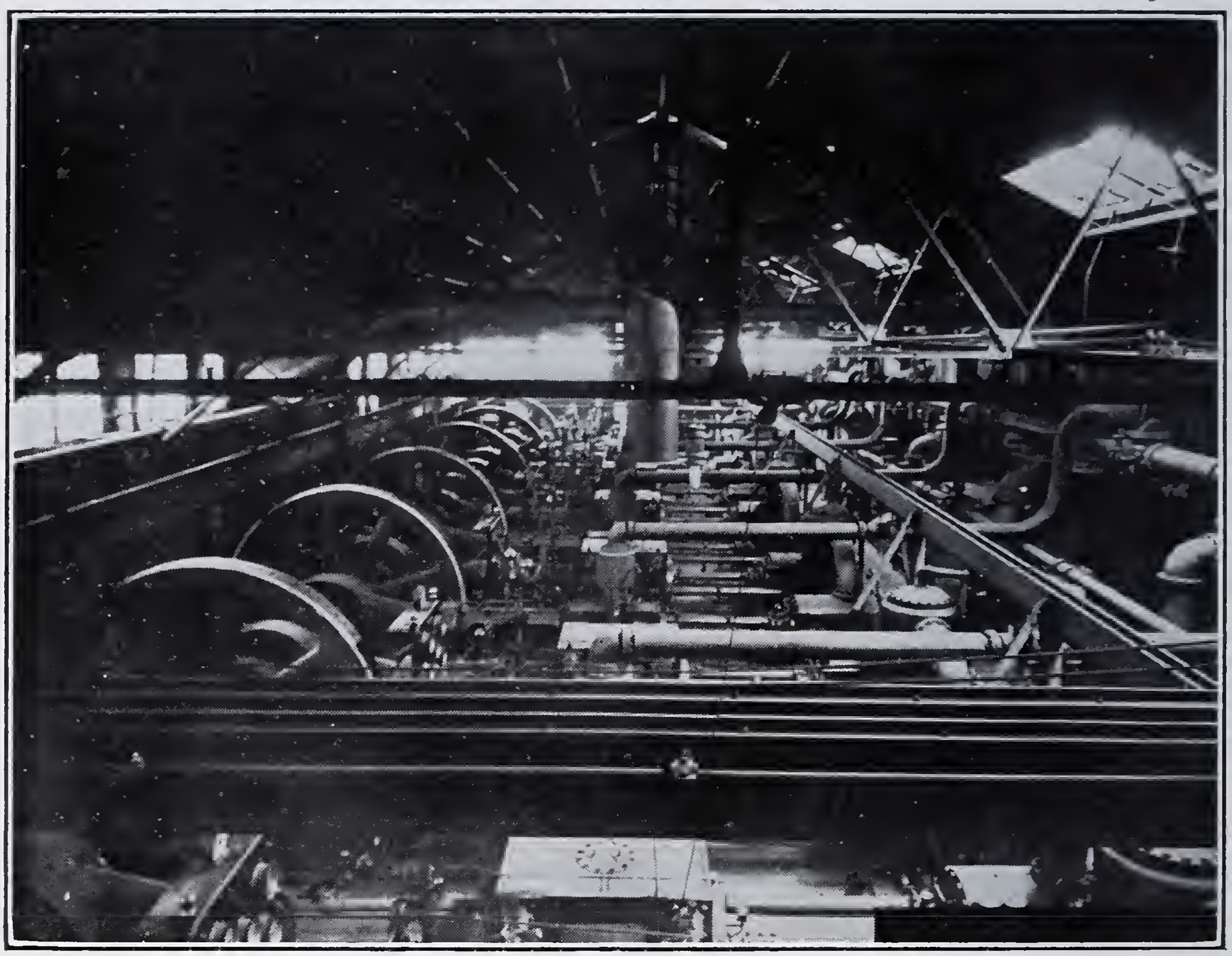


Fig. 4.

of 1000 pounds per square inch for erecting the cast-iron lining. The lower pressure was discharged into an accumulator, so that the pressure would not fluctuate with the pulsations of the engine; otherwise there would be danger of the men getting caught with the segments.

Stirling boilers were used for supplying steam to the plant. These boilers were exceedingly efficient, and a better selection could not have been made. There were six boilers of 500 H.P. each on each side of the river. But in view of the results obtained, without doubt it would have been better if the boilers had been elevated so that the

ashes could be dumped clear of the grates. On two occasions, when the tunnels were making the greatest demand on the boiler plant and everything was pushed to the utmost capacity, three of the grates on the Manhattan side were allowed to burn down with the hot ashes accumulated underneath; the anxiety and hustling to get new grates in and still keep the tunnels from flooding can be imagined.

Surface condensers were used, and as it was feared that the East River water would corrode the tubes, either from chemical action or electrolysis, zincoids were inserted at the entering end of each tube.

Fig. 5.

These consisted of split ferules heavily coated with zinc, and they were eaten away instead of the tubes.

In order to save the boilers from the effects of the oil in the condensed steam, or rather to make it possible to use the condensed steam as feed water, the Masson-Scott oil-separating plant was installed at each plant. About the time this plant was put in, the general practice in New York was to use atmospheric condensers, which waste the condensed water to the river, but the price of city water made it a financially sound proposition to put in the oil separator.

In the separator the oily condensed steam water is treated with alumina ferric, which emulsifies the oil, the greater part being taken off in the scum tank; the balance of the oil being in minute globules in the water is removed on a sand-filter. The water, on passing through the sand, comes out perfectly clear and potable. As the filter becomes coated with the oil-globules the water automatically rises to increase its head, and ultimately reaches a small siphon, which discharges sufficient water into a bucket hanging on two chains

Fig. 6.

that are pulled down by the loaded bucket. The supply from the hot well is shut off by one chain, while the other opens a large valve from a flushing tank which discharges a large volume of water under the filter, and the entrapped air and water is forced up through the sand and gravel until the level of the water above the filter rises high enough to put in operation a large siphon which discharges the scum into the sewer. A float rises with the water and prevents the sand from being carried over into the sewer.

On the Long Island side the caissons had to be sunk under air-

pressure, and Fig. 5 shows the cutting edge of the caissons, with the air-tight floor and the blow-pipe for blowing the water out. The cutting-edge was carried on blocking while the rock was blasted out from under. These were sunk to a depth of 90 feet and sealed water-tight; the air-tight floor was then removed, and the shields were lowered down and built in place, and the floor was put on again at a higher elevation above the shields. After the air-pressure was turned on and plug plates in the side of the caissons were removed under the air-pressure, the shields started on their journey.

Fig. 7.

On the Manhattan side the steel caissons were sunk without air and stopped after about 40 feet, and the shaft was continued in the open without any steelwork. The shields were lowered down and built on wooden cradles, as shown in Fig. 6. Meantime the tunnel was driven toward the water as far as the solid rock permitted, and as soon as the shield was finished it was pushed into the tunnel and the bulkhead built behind it, with the air-locks in place, and the air was turned on. It was then possible to proceed with the tunnel and break through the rock roof into the soft ground.

Figs. 7 and 8 show the concrete bulkhead and the air-locks. The two lower ones are for material and the upper one for the men. It was found that the timber lock was very inconvenient for passing rails, pipes, and lumber, so one of the lower locks was increased in length so that the longest rails and pipes could go through without taking them off the cars. The engineers had a small pipe-lock through which they projected the lines and levels for the tunnel; this work was done so accurately throughout that after the tunnels were finished the divergence from the lines and grades on which the

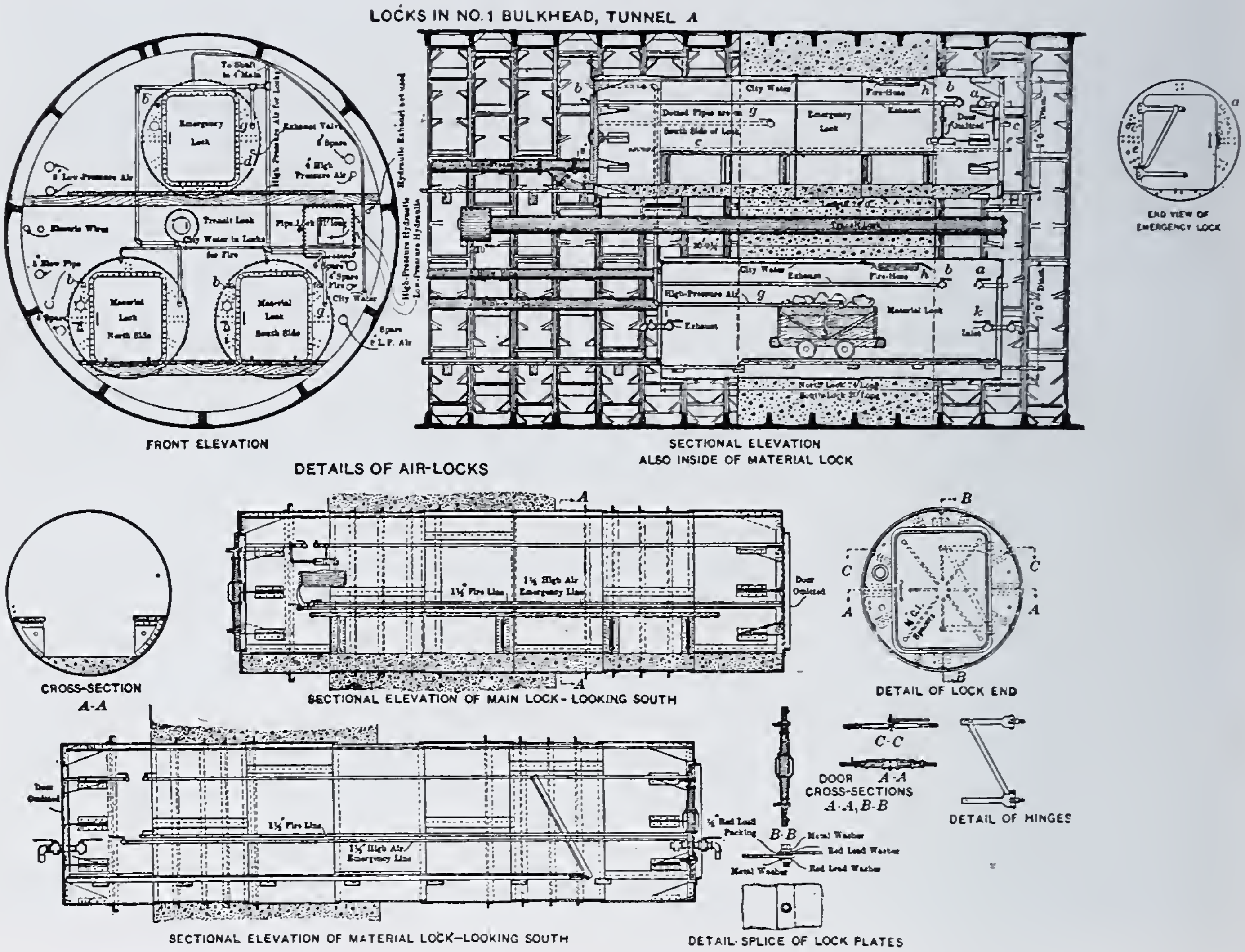


Fig. 8.

contractors bid could all be measured within the circumference of a dime.

On entering the tunnel the first thing that met the eye was the safety curtain, which is shown in Fig. 9. If the tunnel were flooded, the water would rise until it reached the under side of this curtain, then the water would trap the air between the curtain and the air-locks,—like a diving-bell,—so that in case of emergency it was always possible for the men to get back along the emergency gangway under the curtain to safety and on to the emergency lock. There

were two of these safety curtains in each tunnel; when one was being moved ahead nearer the shield, the other one was in place.

Behind each shield there was a traveling stage which was anchored

Fig. 9.

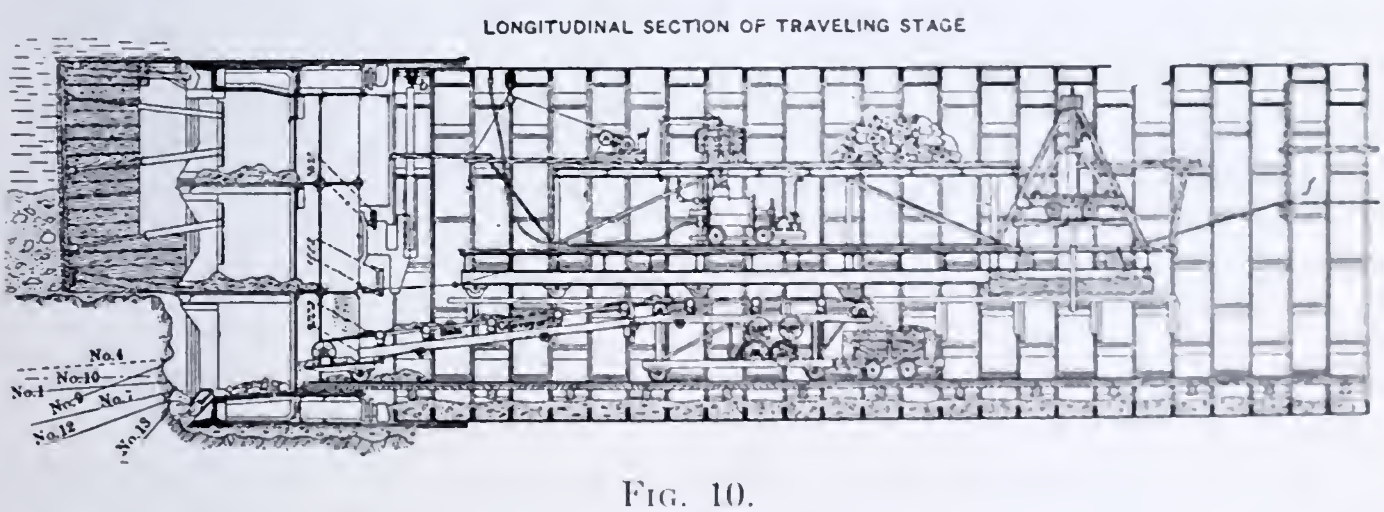


Fig. 10.

to the shield and had an elevator at the rear end for taking up cement and sand for grouting to the upper platform.

Fig. 10 shows the general outline of the traveling stage attached

to the shield by a turn-buckle and traveling with rollers on rails supported by steel brackets attached to the tunnel lining.

The haulage gear, which was driven by electric motors, consisted of an endless rope trailing along the floor with a few supporting rollers. Several designs of grips for attaching the ropes to the cars were tried, but they were abandoned in favor of a light hook chain.

For concreting the tunnel inexpensive electric locomotives of 7½ H.P. were used, the motor pinion geared into a countershaft with a

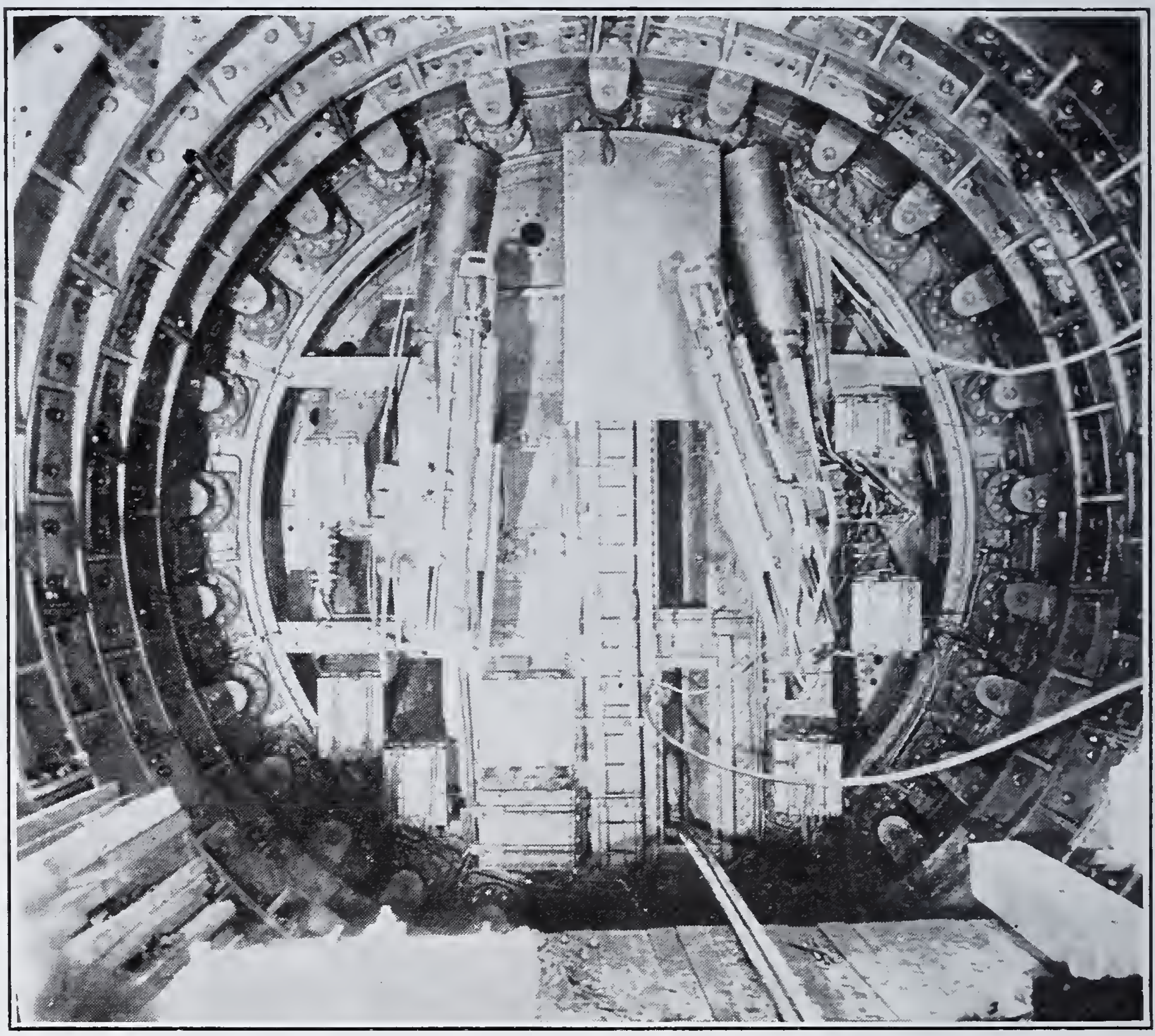


Fig. 11.

sprocket wheel and chain drive to each axle; an overhead wire was used.

Fig. 11 shows the back view of the shield with 27 jackets, each of 9 inches diameter. One shield completely mounted weighed about 300 tons. The erectors, of which there were two in each shield, were operated with 1000 pounds hydraulic pressure. By means of a hydraulic rack on the center pinion the arm was rotated, and on the

arm was a push-and-pull cylinder with which it was possible to extend the arm so that it could reach the circumference of the tunnel.

The shields were designed first all like the Blackwall tunnel shield (see Fig. 12), with the idea that all manner of difficulties could be encountered and overcome. Double diaphragms and air-locks

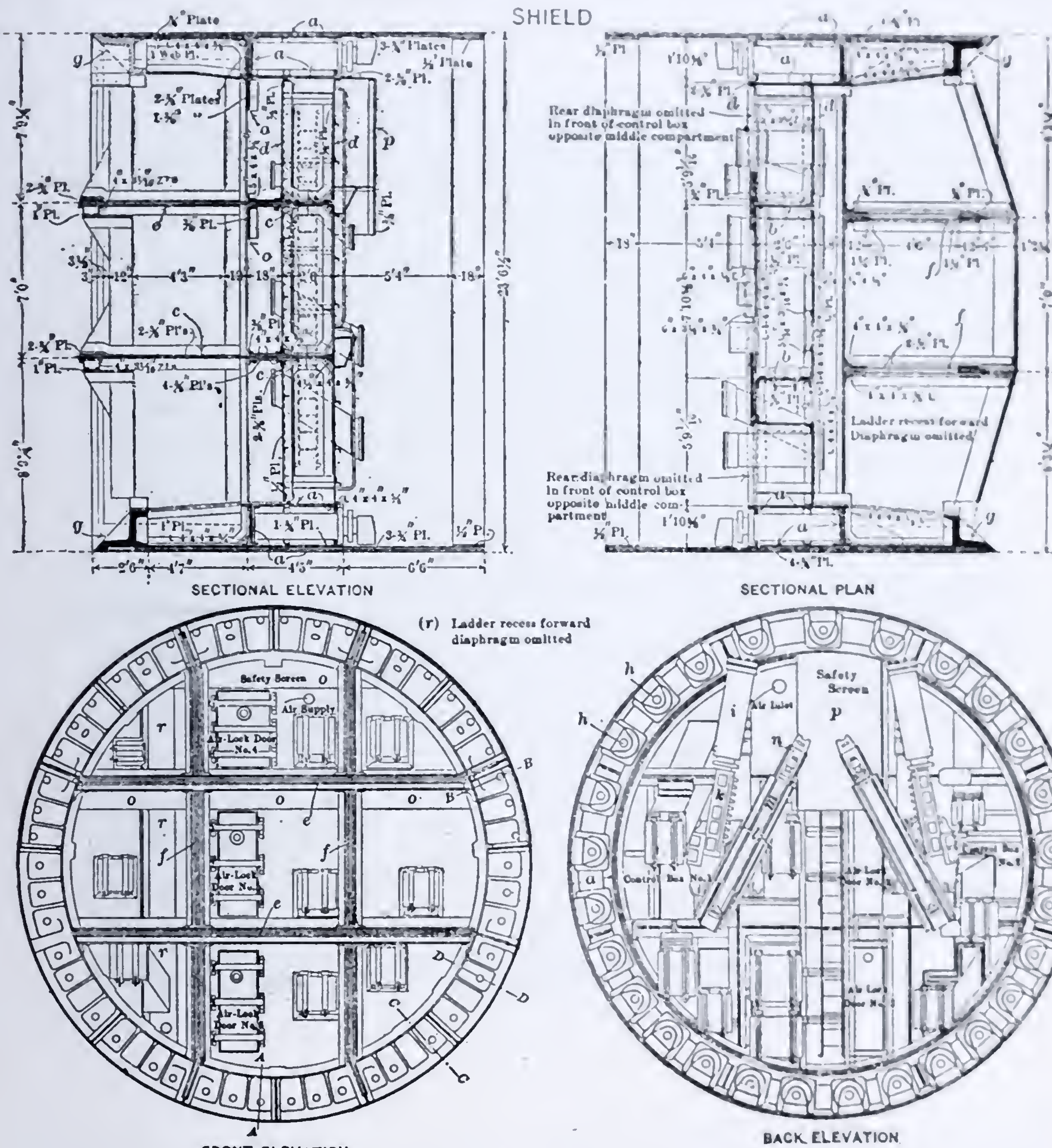


Fig. 12.

through them were provided in order that a differential air-pressure could be used, so that only the men in the face would have to go into high pressure. This scheme might work well in stiff clay, but it could not be applied in a rock tunnel on account of the rough opening in the rock and the difficulty of packing tightly around the shield.

Fig. 13 shows the face of the shield with the extension hood three feet beyond the cutting-edge. The eight under-river shields were built by the New York Shipbuilding Company at Camden. This company also built one of lighter design for the work at East Avenue. There were two horizontal floors and two vertical girders in each shield, dividing it up into nine pockets. The small lock-doors and

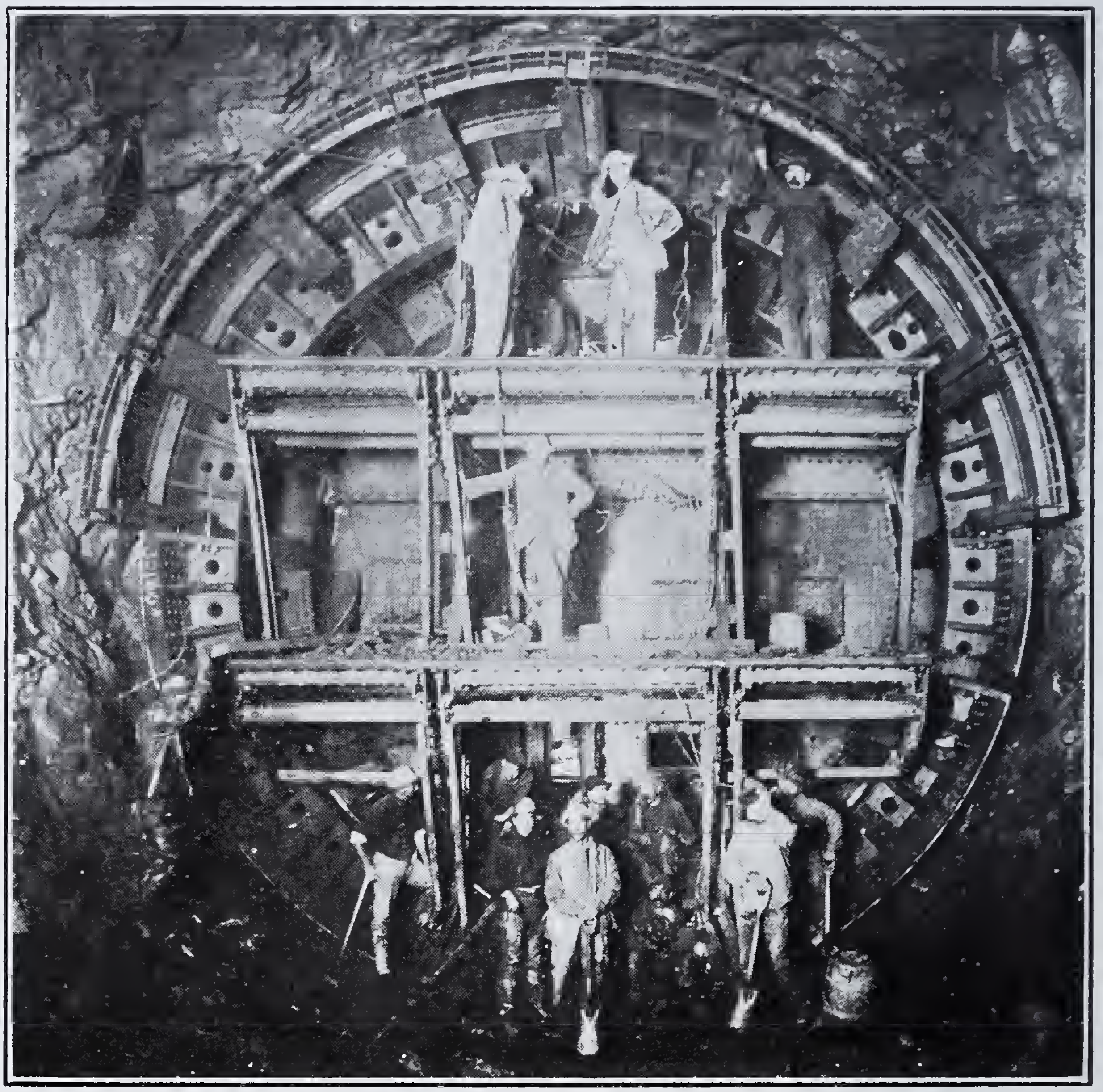


Fig. 13.

shoots were a great handicap in passing rock excavation through—so much so that they were very much enlarged after a little experience.

On the back of each shield was a safety hood that covered the opening into the upper floor, and was designed so that if the water came into the tunnel, it could not rise higher than the under side of this hood, so long as the annular space between the cast-iron lining and the tail of the shield was kept packed with clay or bags. This

was equivalent to having one of the safety curtains right up at the back of the shield.

Fig. 14 shows method of erecting the segments on the upper quarter. The segments were attached to the erector bar by a gadget with a large nut on one plain screwed end, and a flanged spigot on the other; the nut was run back far enough to insert the gadget, and the nut was spun by hand very quickly to lock it in place. This is a very

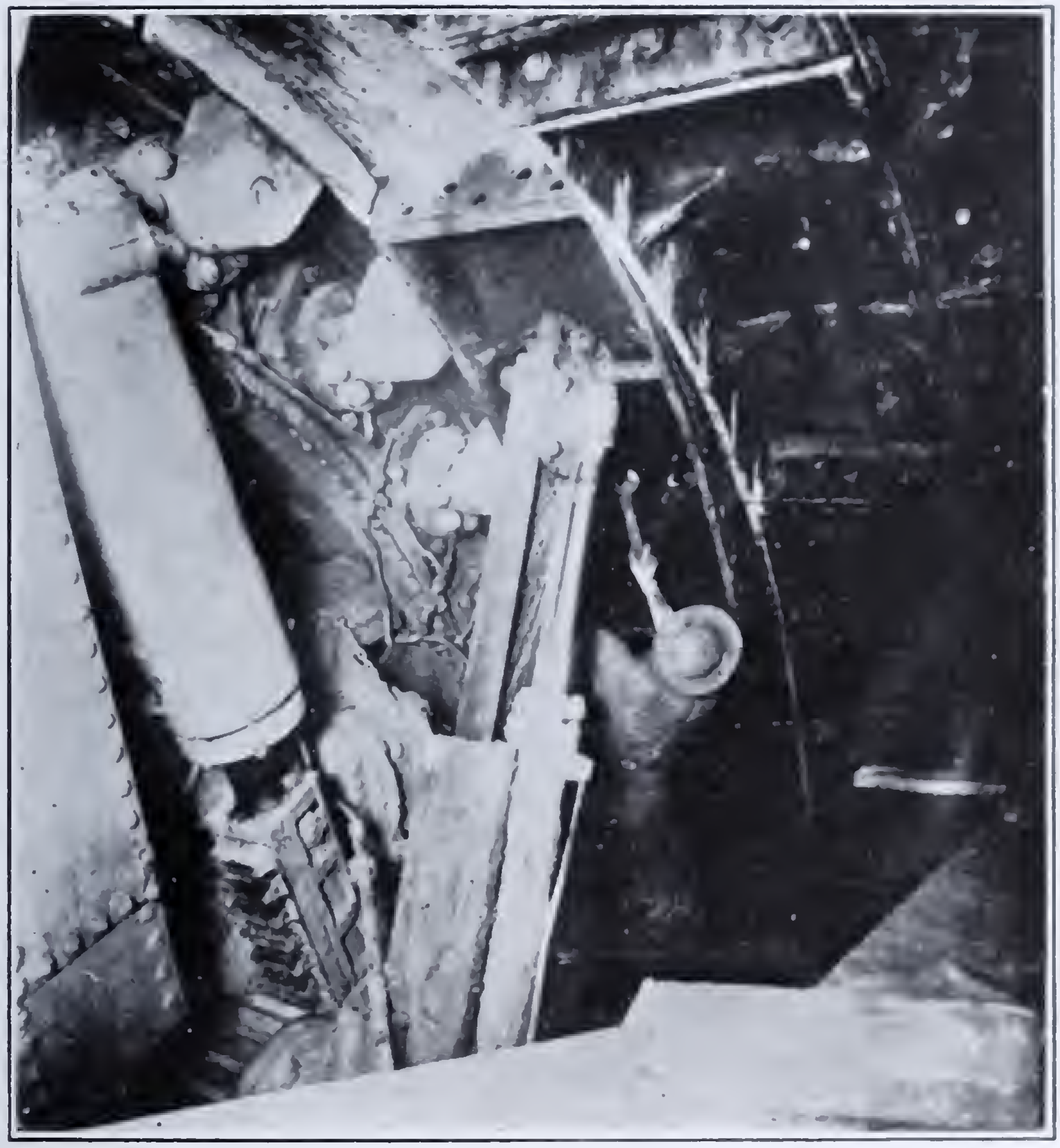


Fig. 14.

effective way of lifting the segments and saved the expense of cast-iron lugs on each segment. The cast iron in the four tunnels represents about 100,000 tons; each segment weighed about one ton, so that about 100,000 lugs were saved.

Fig. 15 shows the method of erecting lining in the lower quarter.

Fig. 16 shows the method adopted at East Avenue, where there was no shield. The erector was carried on a platform driven by a

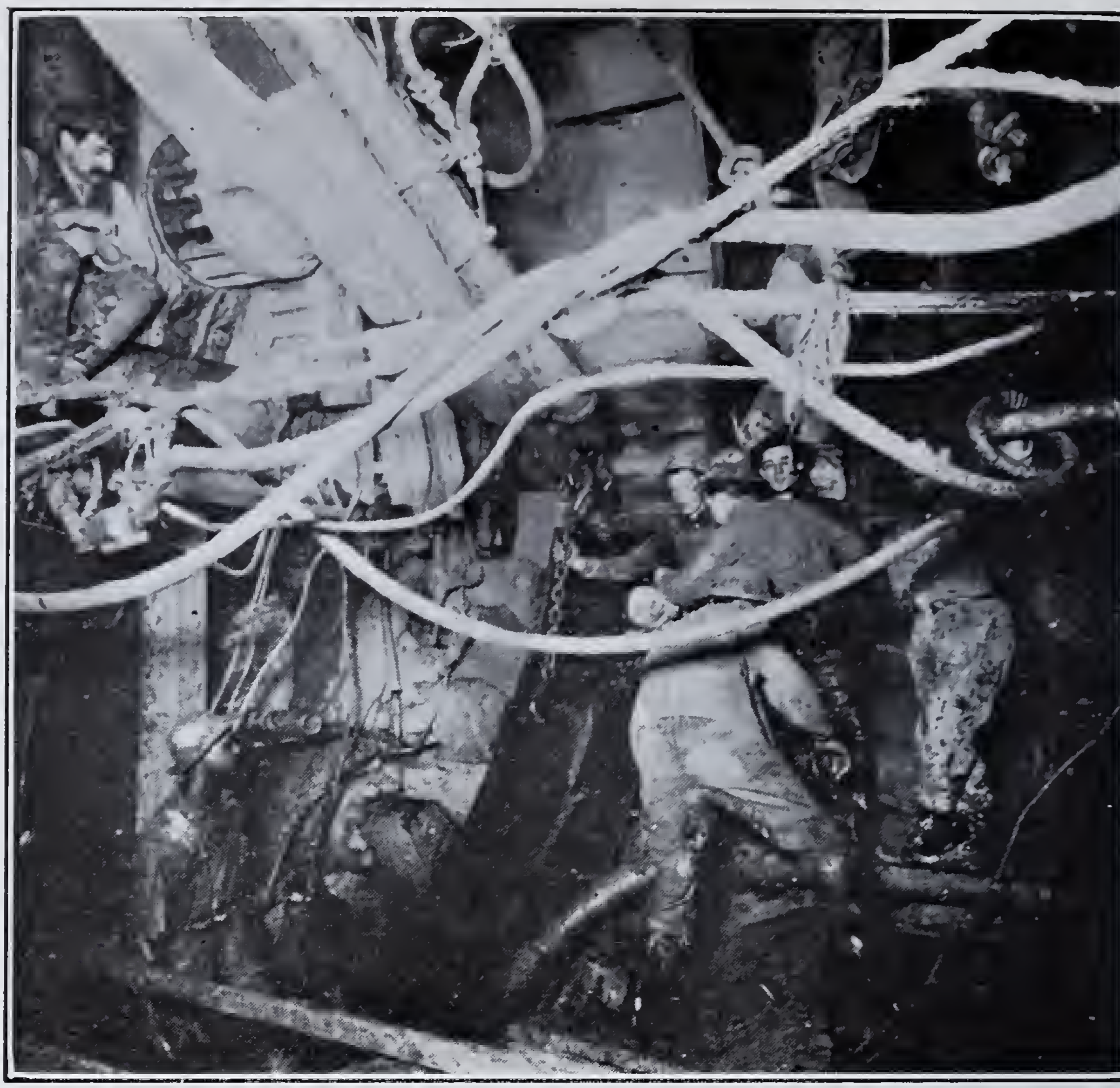


FIG. 15.

FIG. 16.

three-cylinder air-engine. It had a double arm, enabling it to reach all the way around the circumference, although the arm traveled only a little more than half-way.

The contractors had a special inspector on each shift all the time to see that the rock was trimmed away in front of the shield before a shove was made so that the shields should not be crippled. In spite of this, on three or four occasions the cutting-edge was pushed up on an incline of rock, which was almost imperceptible, and Fig.

Fig. 17.

17 shows the result. The crippling on this photograph is about four inches, and extends back about two feet under the shield, and the rock had to be mined out underneath the shield for about three feet so that when the shield moved ahead again there was no more of the inclined plane to cripple the shield tail. After sawing away the crippled part, the cutting-edge was brought out to its true curve by a heavy cast-steel patch.

The method of tunnel driving adopted in an all rock section is shown in Fig. 18. Sometimes the heading was driven in the center

and sometimes in the bottom, but the quickest advance was made from the center, and the roof was shot down on a projecting platform and loaded on to cars.

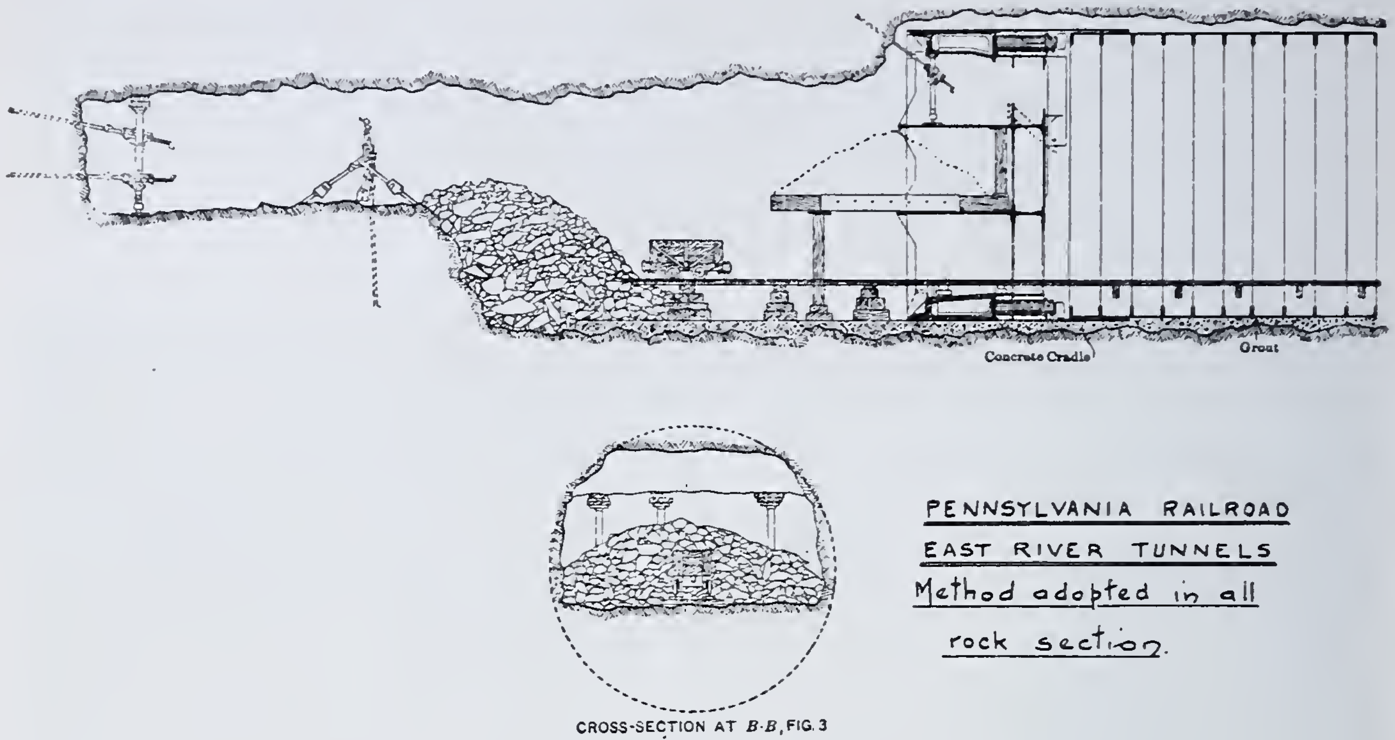


Fig. 18.

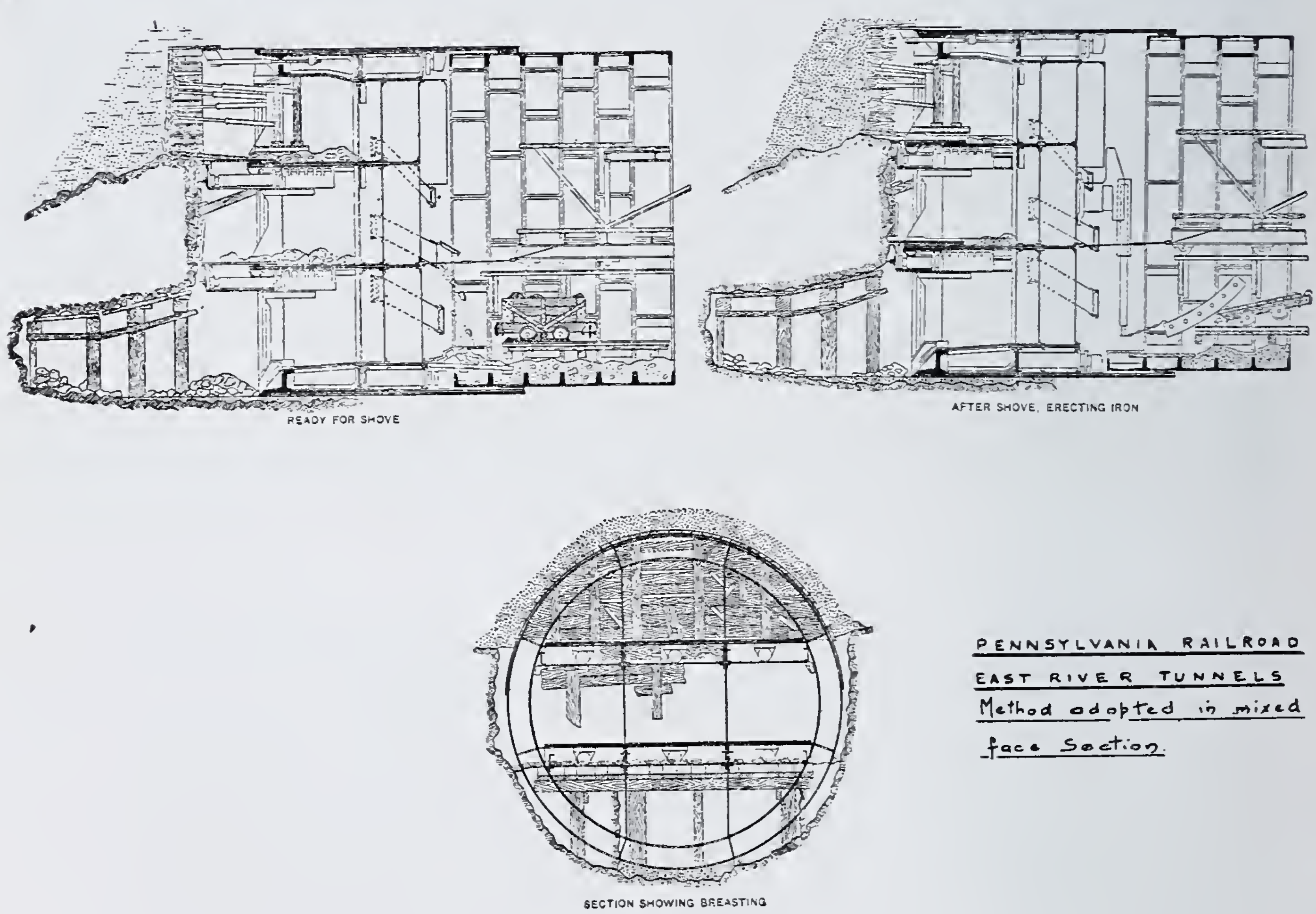


Fig. 19.

The all-rock speed was about 25 feet of completed tunnel a week. In a mixed face 8 rings of 2′6″ each in seven days was considered

very good work, or 20 feet. Fig. 19 shows the method adopted for a mixed face. Where the rock was high enough to permit a bottom heading, it was driven in advance of the shield and a concrete cradle placed for the shield sliding on. This diagram shows how the bottom heading was reduced in height as the soft disintegrated rock was met near the overlying quicksand. In the soft top sufficient was mined out for two shoves, or five feet. When the bench was cleared, it was drilled and blasted and the breast-boards were held in

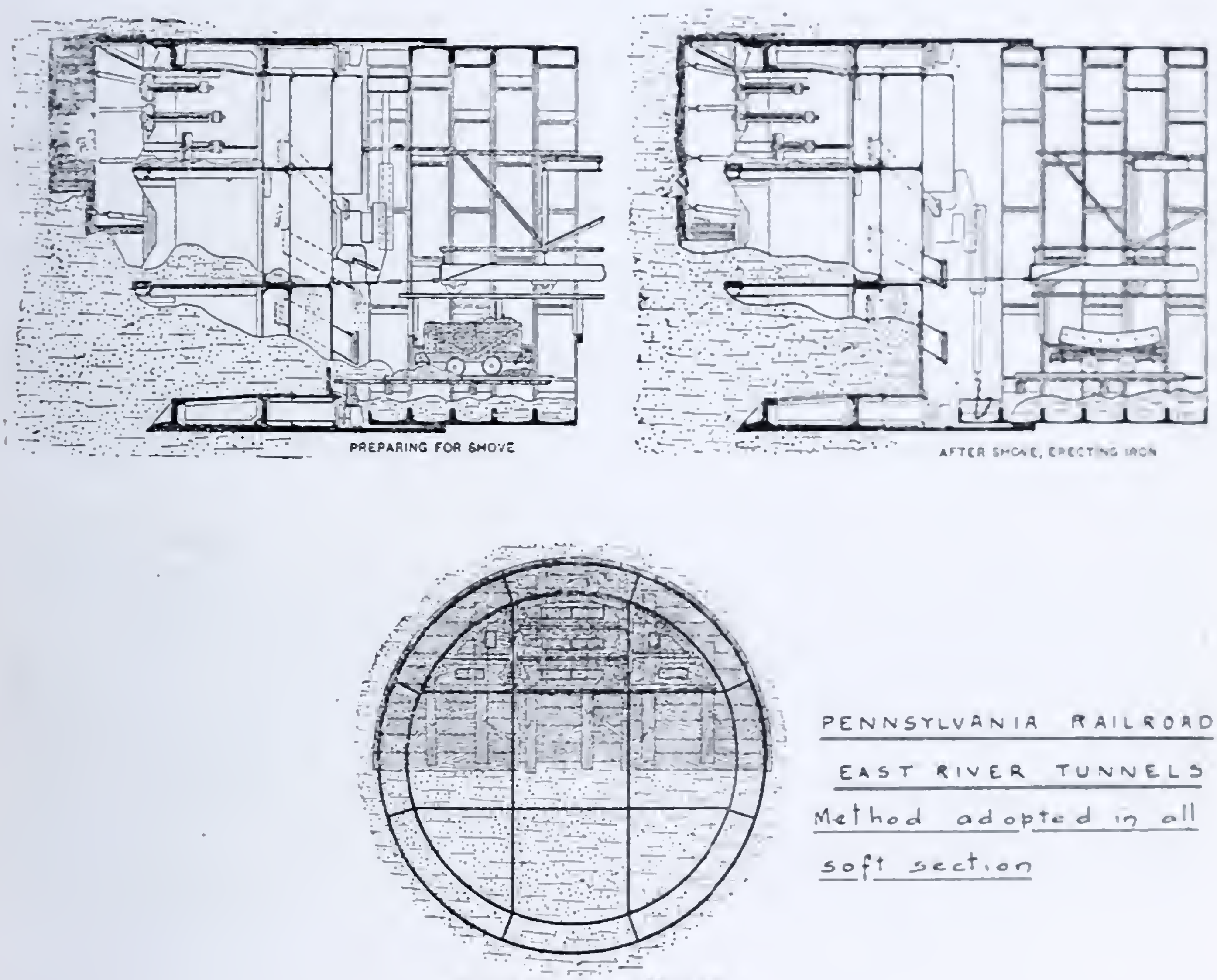


Fig. 20.

place by telescopic pipes or guns with friction screws, so that as the shield moved forward there was just enough friction to keep the braces tight.

When a bottom heading was no longer possible, the same methods were adopted in mining out the top and drilling the bench, excepting that in order to hasten placing the concrete cradle, immediately on completing a shove the drills were started putting down cut holes in the invert.

Fig. 20 shows the method adopted in the all soft face, where speeds of 75 feet per week were reached.

In order to take care of the difference in pressure between the top and the bottom of the shield, which in 23 feet is about 10 pounds, the contractors were faced by the same problems encountered in the Blackwall Tunnel. If the pressure was raised high enough to drain the quicksand in the bottom and prevent the shield sinking, the roof was blown off, and if the pressure was kept low enough to keep the roof safe, the shield sunk in the quicksand, so that a clay

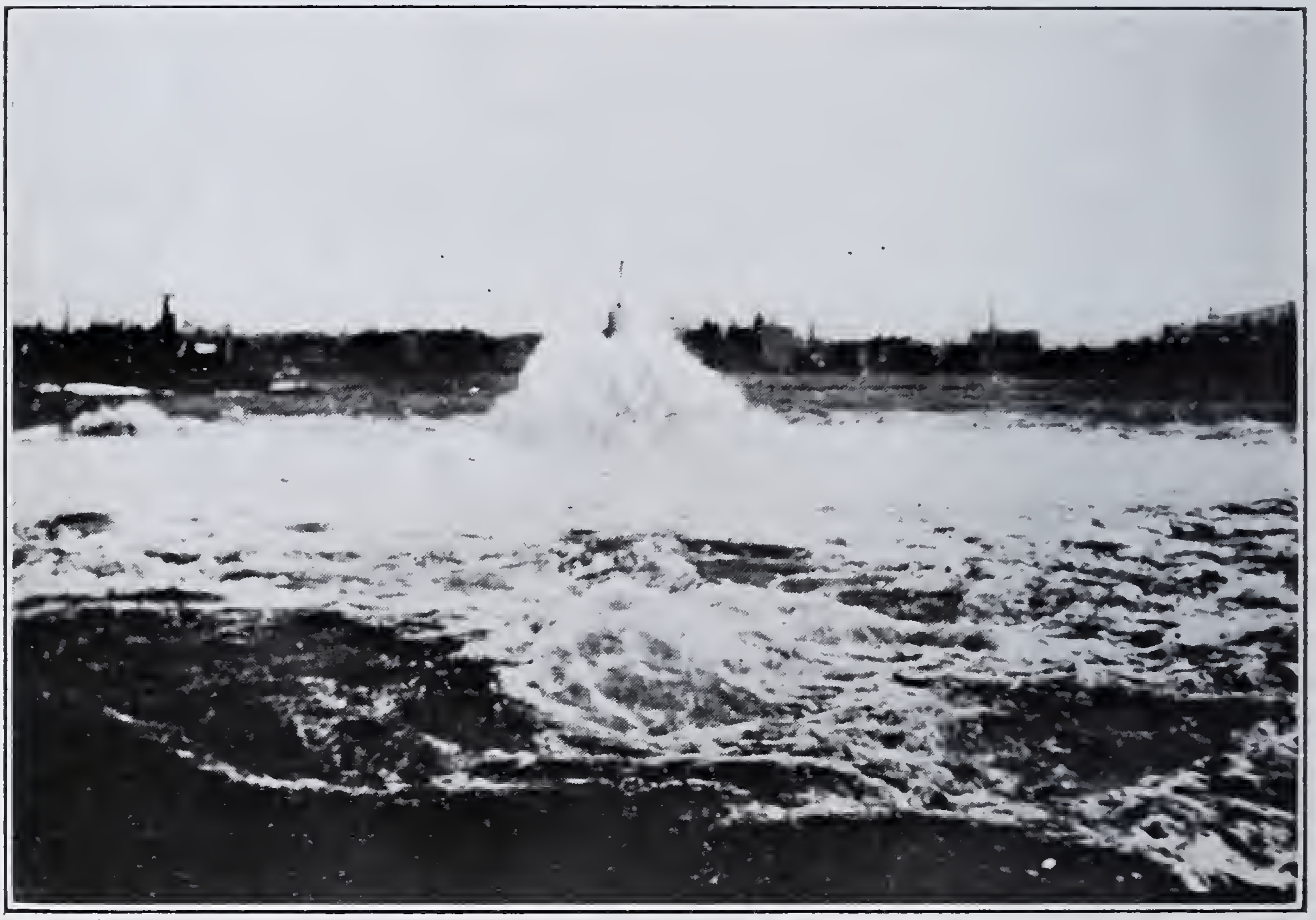


Fig. 21.

blanket was used to the extent of 500,000 cubic yards to reinforce the bed of the river. Under-water rights were purchased at Haverstraw on the Hudson, and the clay was dredged and dumped in the East River over the tunnels. As the tunnels progressed the blanket was redredged into dump-scows and dumped on ahead of the tunnels.

In spite of this expenditure "blows" were very frequent, and Fig. 21 shows the effect of a "blow" of 20,000 cubic feet of air per minute, or 2400 H.P. These "blows" were powerful enough to deflect one of the largest ferryboats off its course.

Fig. 22.

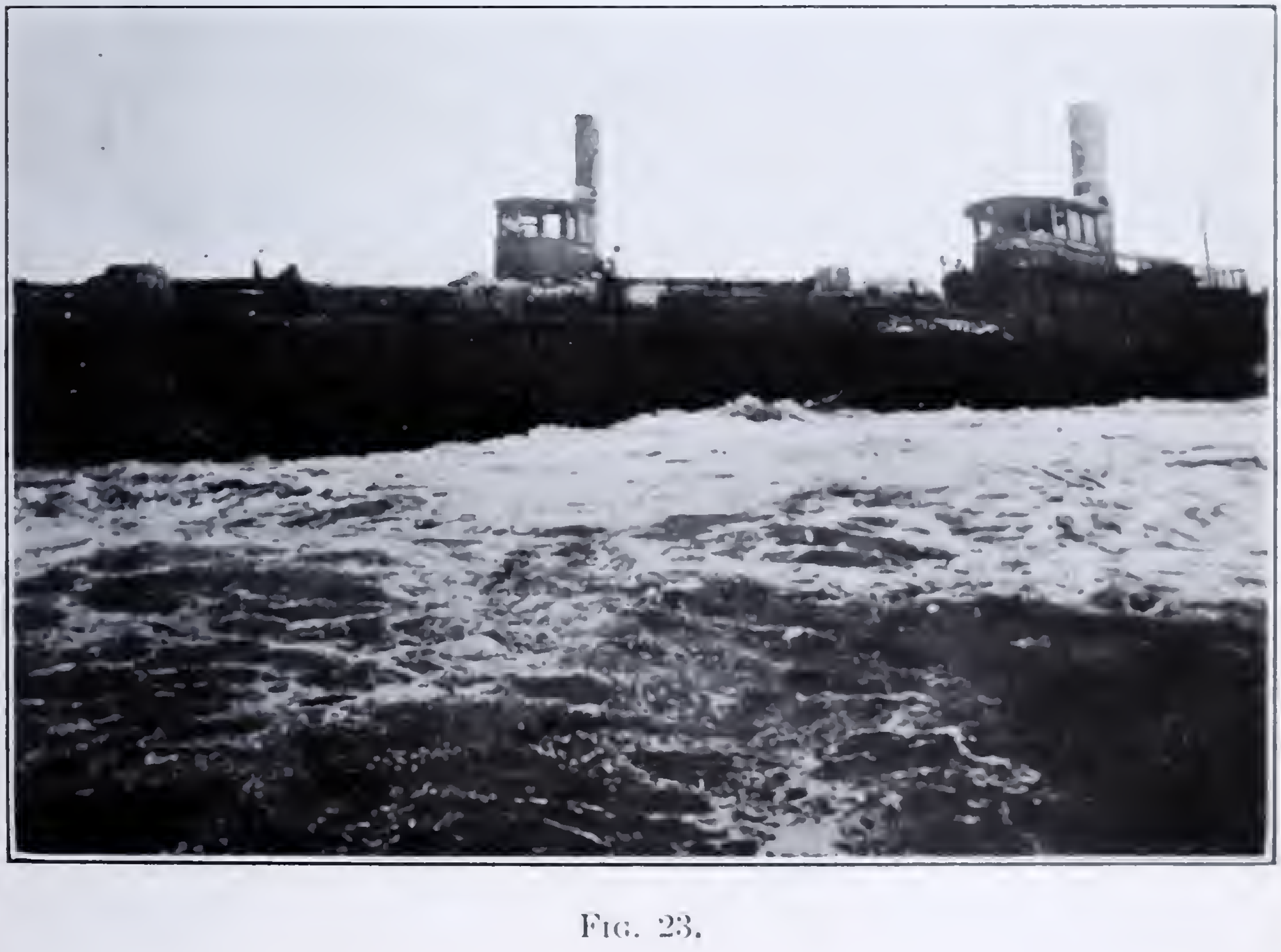


Fig. 23.

Quick-setting lime grout was used with excellent effect for stopping "blows" in conjunction with the clay blanket.

Fig. 22 shows two tug-boats forcing a 700 cubic yard scow over the same "blow," while Fig. 23 shows the "blow" after the scow was dumped.

Fig. 24 shows the dredging plant for handling the clay blanket. In spite of these serious "blows" only one tunnel was flooded and two men were drowned, all of which occurred before the clay blanket was completed.

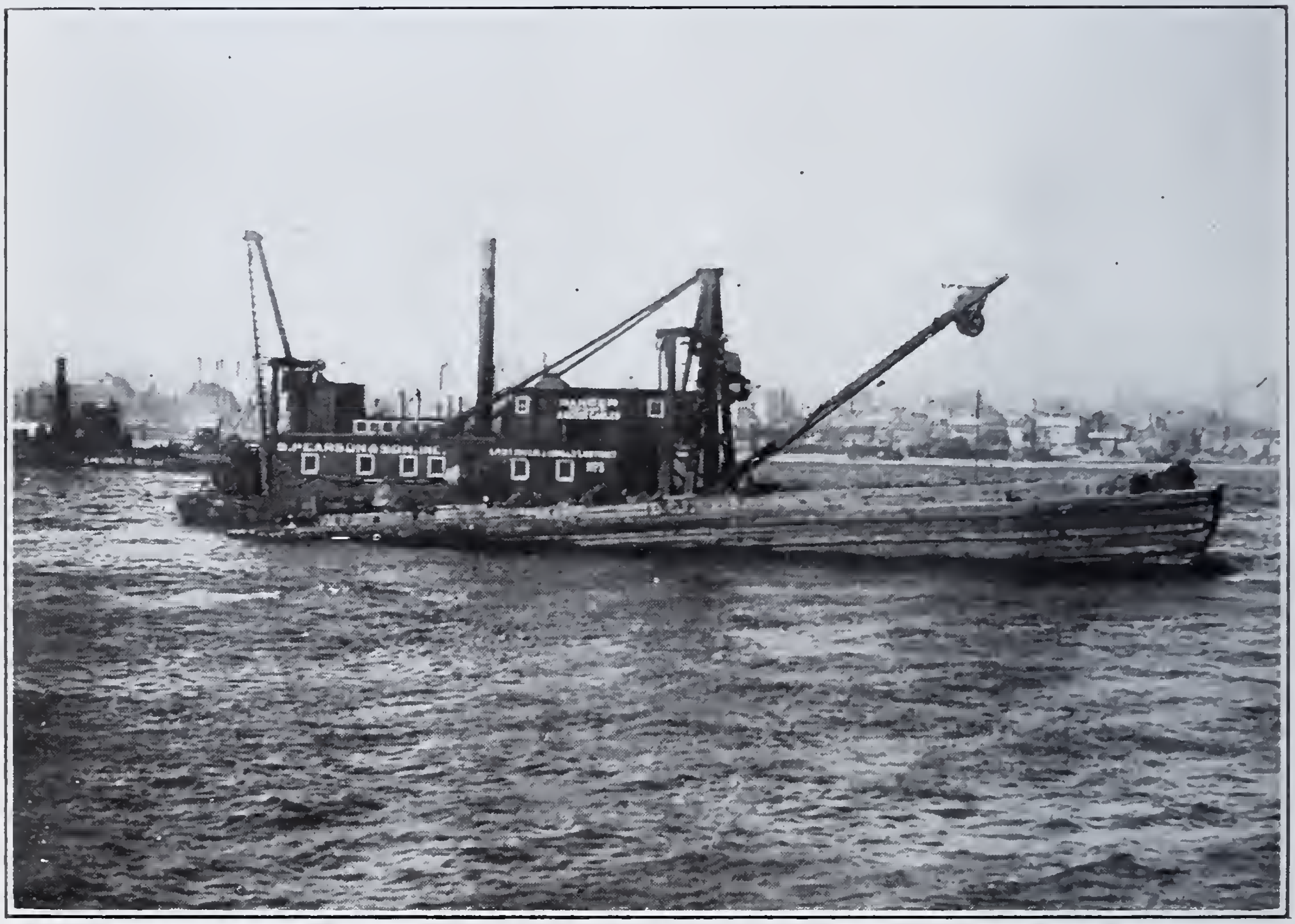


Fig. 24.

Fire was a great source of danger in the tunnels, and resulted in considerable loss of life. On Sunday, after pay-day, work was not attempted, but two men were detailed to watch in each tunnel. On one occasion one of the watchmen left the tunnel, the other fell asleep on a pile of hay while smoking a cigarette and was suffocated by the fire he started. When the first shift tried to get through the lock on Monday morning, the smoke coming in at the air valve compelled the men to give up. It was not until a high-pressure air-hose was connected to the exhaust valve that they were able to lock in the sur-

plus air and drive the smoke away from the lock entrance. Fortunately, they were able to carry out the dynamite before the flame reached it and to put out the fire.

After that experience a high-pressure connection was permanently fixed on each air-lock, and in addition a water service also, so that water and high-pressure air-services were available for fighting fire.

A frequent source of fire was searching for air-leaks in the polling boards in the roof of the tunnel, especially if there had been a "blow" and the air was whistling through the polling boards, and men were detailed to plug up the joints with clay.

Some one was generally foolish enough to take a candle to see if the escaping air sucked the smoke and flame. The flame is drawn up out of sight and reaches the packing and dry hay that are used for filling cavities. Such a fire would smoulder for days, and the shield would become so hot that one could not touch it with the hand.

To meet such cases holes had to be drilled through the skin for a hose connection.

But neither fire nor water, nor falling rocks nor dynamite, constituted the greatest source of danger, but that strange disease called "bends," or "caisson-disease." Not much trouble was experienced until the pressure reached 29 pounds, when two men, against orders, went into the tunnel without being first examined by the doctor. They died within an hour after coming out, when the force was scared and became disorganized. By the time the pressure reached 35 pounds the best men were either scared or disabled by the high pressure, and with a force of some 2500 men it can be imagined what it meant to rebuild the organization. Everything possible was done to minimize the effects of the air-pressure. There were five doctors, four hospital orderlies, and six medical air-locks on the works; stringent regulations were enforced as to medical examinations and lengthening the time of decompression.

It was not until after Dr. Haldane, who was investigating caisson-disease for the British admiralty, had published the results of his researches that much light was thrown on this strange disease. He grasped the subject in so masterly a way that divers were enabled to go down in a pressure of 92 pounds per square inch, or 208 feet of salt water, without injury.

He found, in looking up the subject, that up to 19 pounds pressure no cases of disease had ever resulted, and he argued from this: if one could come out of 19 pounds gage pressure, or 34 pounds abso-

lute, to 15 pounds absolute without harm, then one could reduce the absolute pressure by 50 per cent. and do no harm. So at a depth of 92 + 15, which is 107 pounds, one could raise a diver up to 53 pounds absolute and hold him there long enough for the pressure in the blood to fall to 72 pounds absolute and go on decompressing at such a rate that the blood-pressure is never more than 19 pounds above the pressure in the helmet, or on reaching atmosphere a blood-

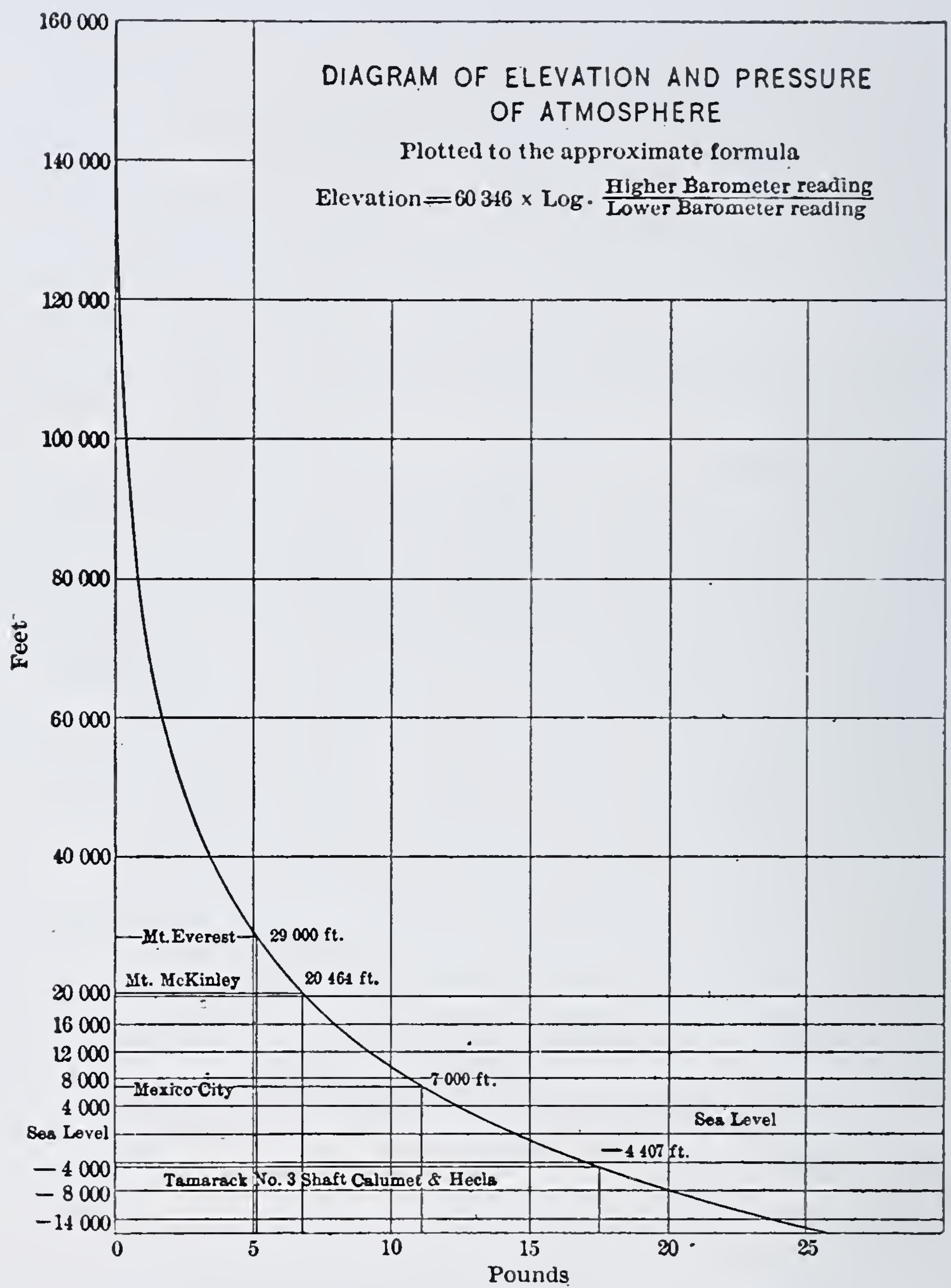


Fig. 25.

pressure of 19 pounds gage. From this he evolved his well-known stage decompression method.

Most people have a vague dread of compressed air, forgetting that they are now under a pressure of 15 pounds.

Fig. 25 shows the varying atmospheric pressures at different altitudes. The greatest natural air-pressure is found at the bottom

of the deep shaft of the Calumet and Mount Hecla mines, while the lowest pressure is found at the top of Mount Everest, the range between these two points being $12\frac{1}{2}$ pounds. Even at Mexico City there is a $3\frac{1}{2}$ pounds lower pressure than at the coast. On the Canadian Pacific Railway, in the Rockies, one can readily notice a sensation in the ear-drums, owing to the effect of the change in pressure. When men climb mountains they are decompressing, and they have to climb slowly and by stages. In compressing, on the other hand, they can go down quickly and with little work, so that from nature we learn that it is safe to enter air-pressure quickly, but decompression must be done slowly and accompanied by exercise.

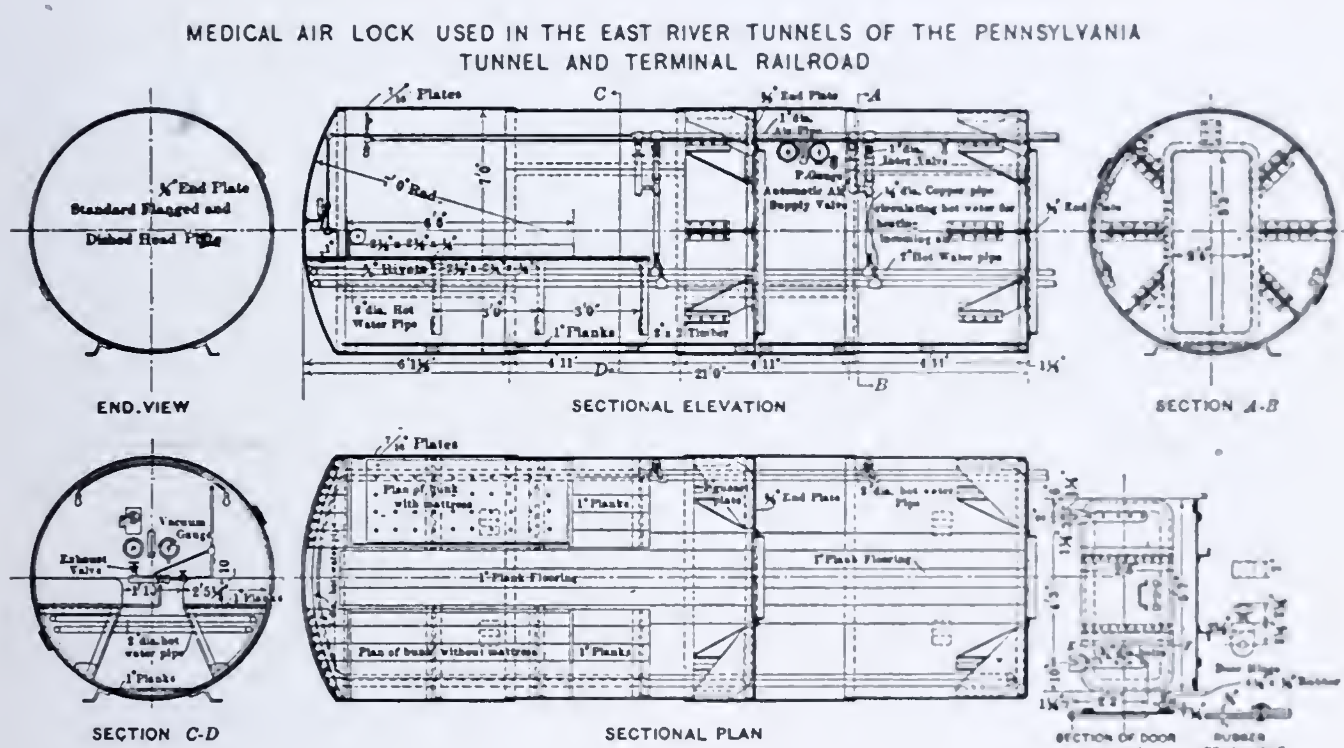


Fig. 26.

The effect of compressed air on the blood may be illustrated by a soda-water bottle that is aërated. If the cork is let out quickly, the contents will bubble over and be spilled. On the other hand, if the bottle is held on its side to give a greater surface to the water and the cork is eased out gently, none of the contents will be wasted and only minute bubbles will appear. On being immersed in compressed air the blood and tissues are charged and absorb the air, so that if the pressure is reduced suddenly, the blood will froth up and the heart, which is a pump, will draw air and lose the suction so that the circulation stops. In other words, "bends," or "caisson-disease," results in one of its many forms. The writer has seen two men who, to all intents and purposes, were dead, but who, upon being placed

in the medical air-lock under pressure, immediately sat up and asked how they got there.

Fig. 26 shows the design of the six medical air-locks, consisting of an inner chamber and an air-lock. The patients were laid on the bunks in the inner chamber, and it was possible for the doctor to pass in and out through the lock to examine them without interfering with the pressure. They were designed by Mr. Moir.

In order to determine the length of time necessary to give the degree of safety advocated by Dr. Haldane, and also to investigate his theory, the writer made what might be called the Sand Hogs Chart, as shown in Fig. 27. This shows graphically how each particular

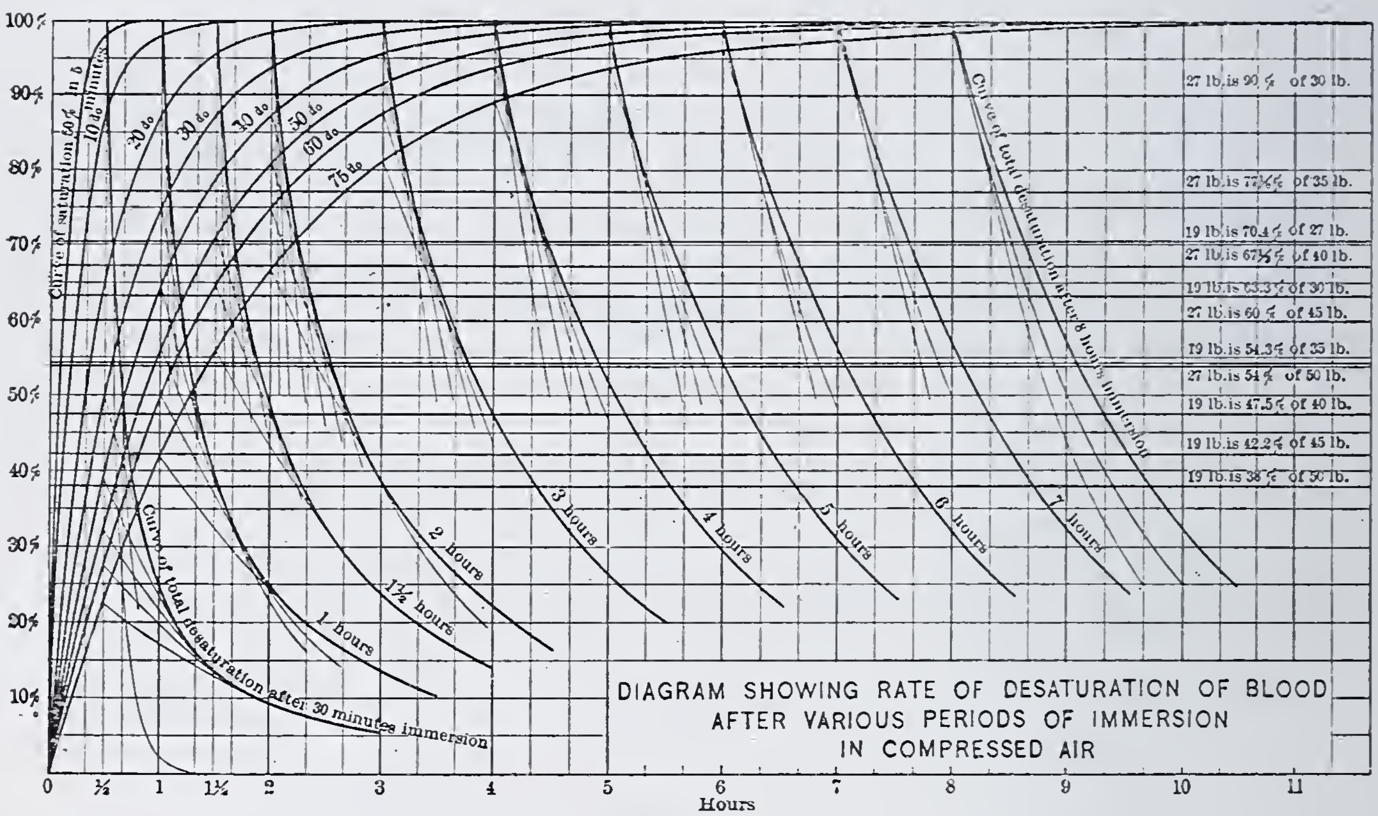


FIG. 27.

part of the body is saturated with air while under air-pressure. Some parts are saturated 50 per cent. in five minutes; others in ten, twenty, or thirty, and so on up to seventy minutes. On the same curve are plotted desaturation curves, showing the time it takes for the air in the blood to drop in pressure after being in the air-chamber from one hour up to eight hours, and from this is made the investigation of the time of decompression necessary to take care of the men.

As a general rule caisson-disease is very mild up to 25 pounds pressure, and as no fatal results occurred on the East River tunnels at this pressure, it was suggested that it would be safe if the blood-pressure never exceeded the lock-pressure by this amount, and as at 27

pounds nine minutes is necessary to allow the blood-pressure to fall to 25 pounds, from this is built up Fig. 28, showing the period for different pressures, always allowing the blood to have within it an air tension of not more than 25 pounds.

After the tunnel driving was completed it was necessary to remove some defective segments in the invert in quicksand, and to make the

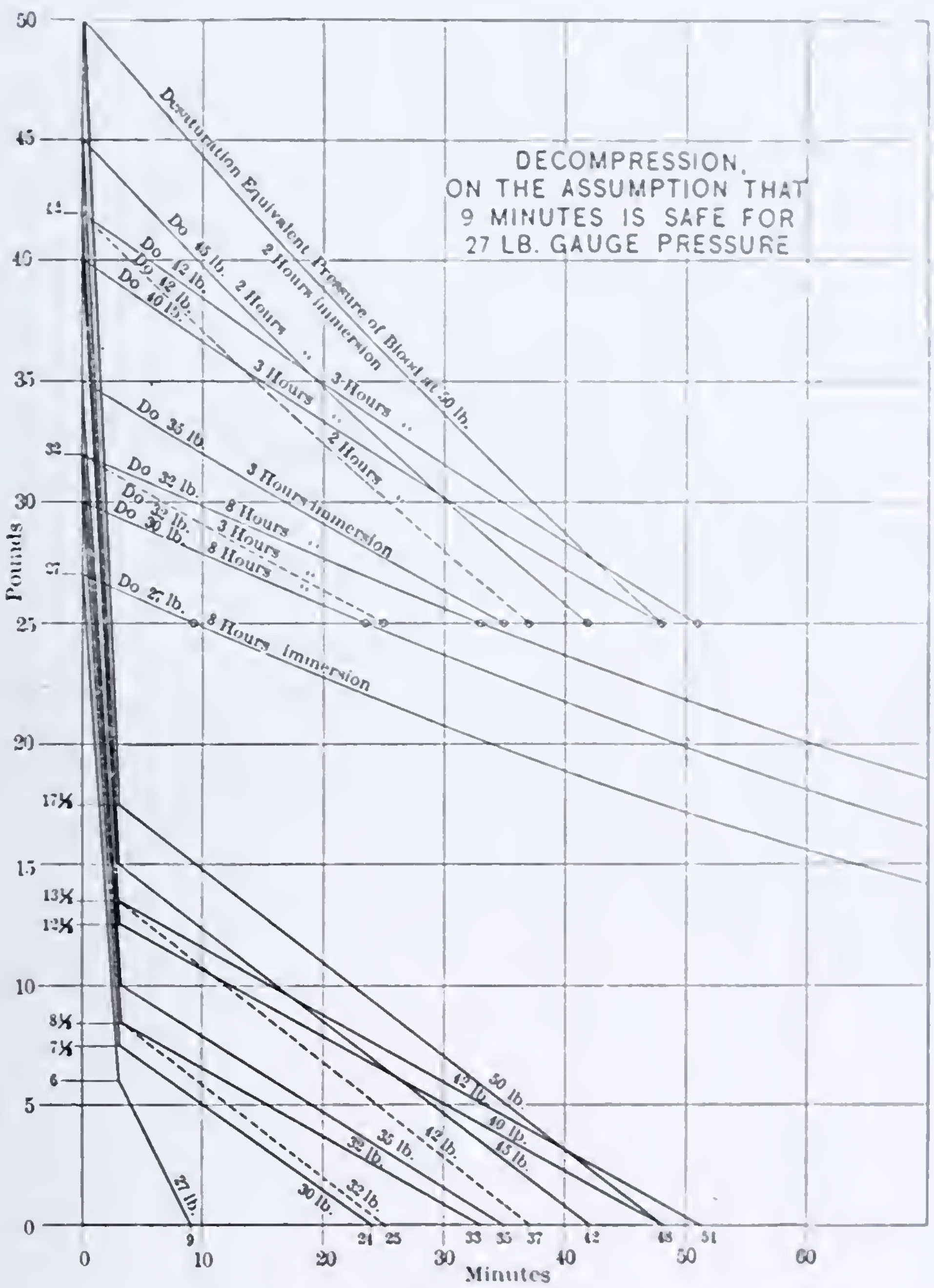


FIG. 28.

operation safe the pressure was raised to 40 pounds gage pressure. Fortunately, there were three sets of air-locks for the men to go through, and it was determined to decompress on Dr. Haldane's principle.

In the first lock the men took five minutes to reduce the pressure from 40 pounds to 29 pounds; meantime the blood-pressure had fallen

down to 39 pounds. Between the first and second air-locks the men had to walk along the tunnel, the pressure being 29 pounds, while the blood-pressure fell to 37½ pounds. In the second lock they took seven and one-half minutes for a fall of pressure from 29 to 12½ pounds, when the blood-pressure reached 35 pounds. Then followed another walk of ten minutes in 12½ pounds, when the blood-pressure fell to 32 pounds. In the third lock they took fifteen minutes for a fall from 12½ pounds to atmosphere, by which time the blood-pressure was down to 27 pounds, while the atmosphere was 15 pounds.

So that although in all forty-eight minutes was taken to decompress, these men on emergence were doing the equivalent of coming

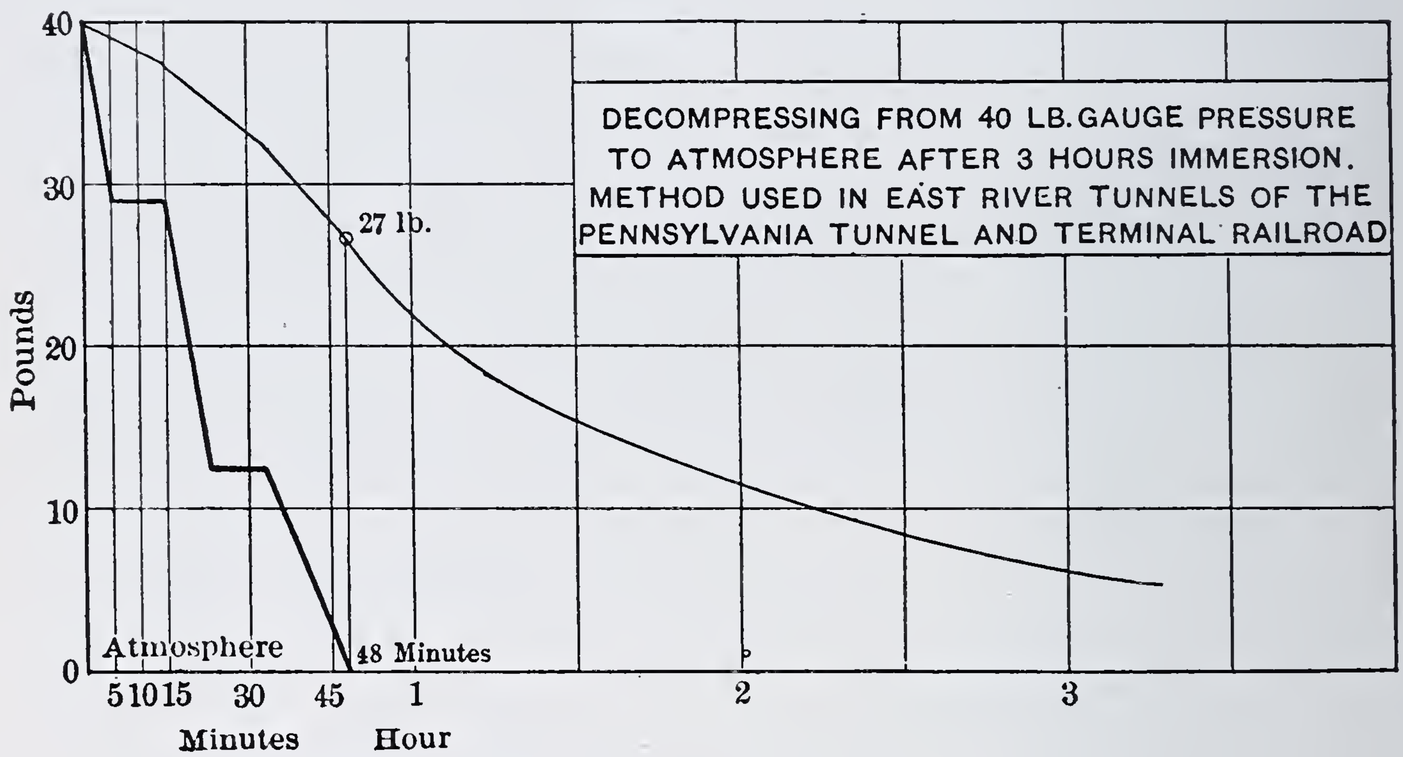


Fig. 29.

out of 27 pounds instantaneously without any bad results. This is all shown graphically in Fig. 29, and it will be seen that two hours after coming out there was still five pounds blood-pressure, which accounts for what are called "deferred cases of caisson-disease."

As a result of this method there were no deaths, but just simple cases of "bends," —generally slight,—and all pain disappeared after a short time spent in the medical air-lock.

In order to make the decompressing period automatic a decompressing valve was designed which automatically reduced the pressure from 35 pounds to atmosphere in fifteen minutes and which was a great help.

The New York State Legislature has passed a law which states that two minutes must elapse for decompressing each 3 pounds in pressures

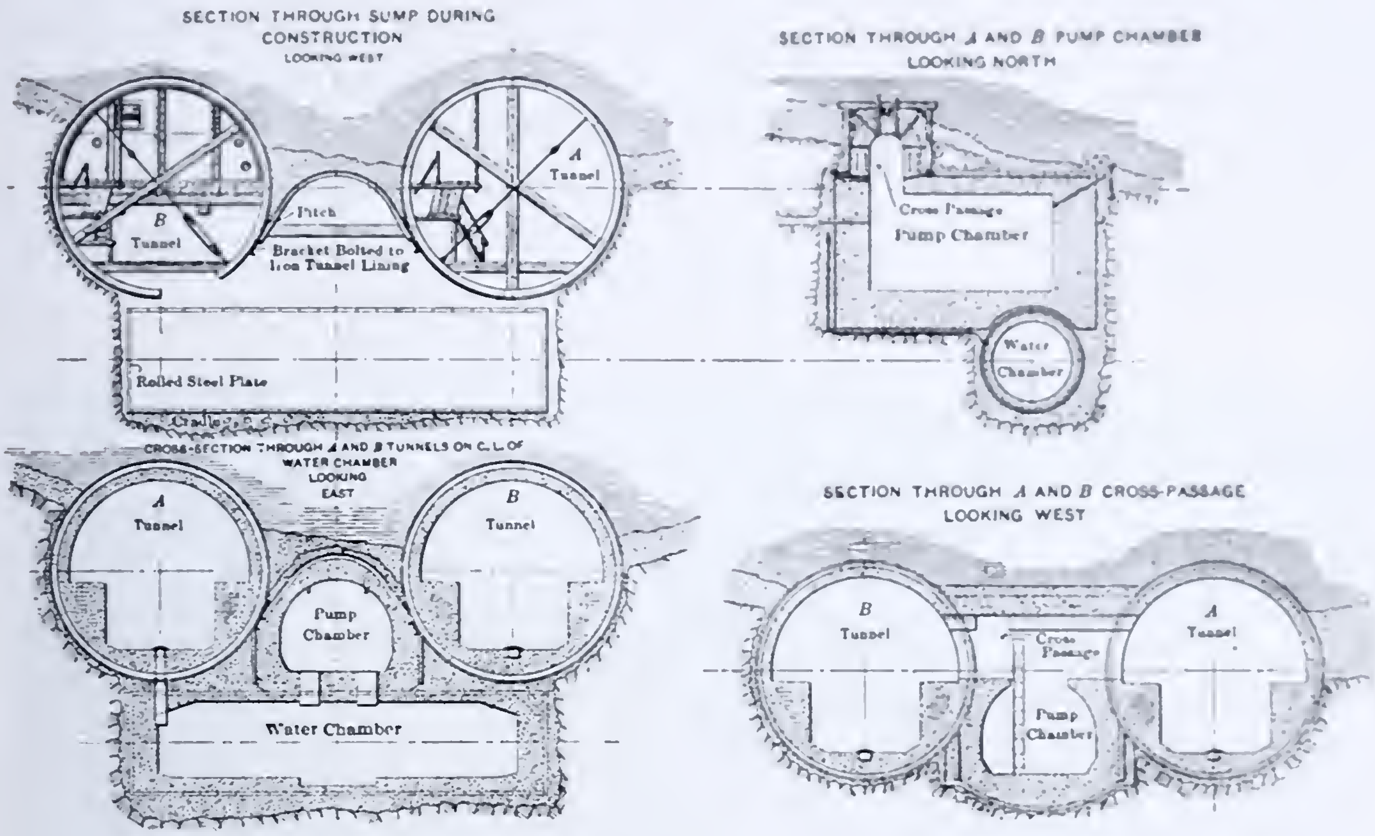


Fig. 30.

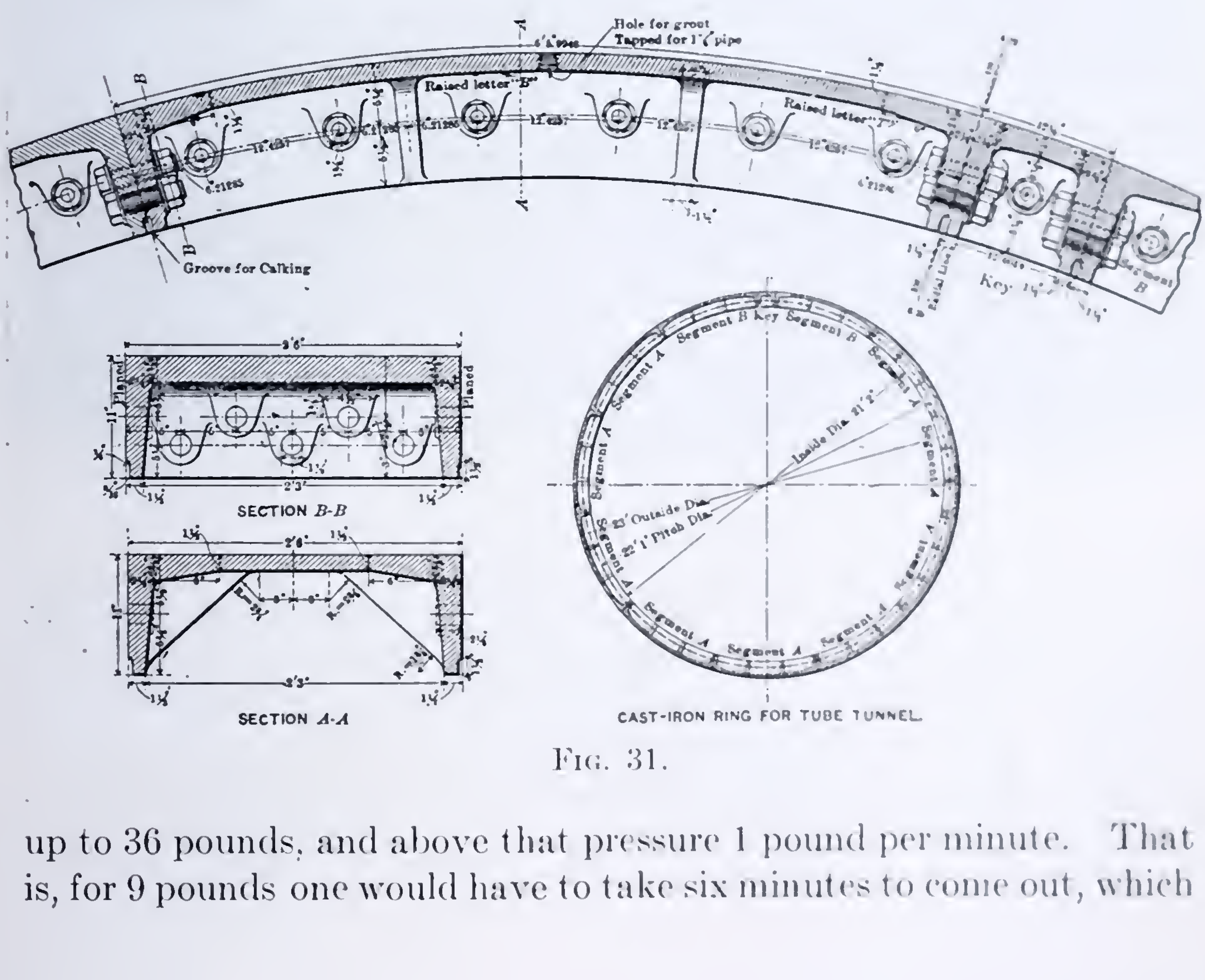


Fig. 31.

up to 36 pounds, and above that pressure 1 pound per minute. That is, for 9 pounds one would have to take six minutes to come out, which

is ridiculous, while for 50 pounds one would have to take fifty minutes, which is longer than the stage method, while the State method only reduces the blood-pressure to 32 pounds, so that it is not so safe as the stage method.

In order to drain the tunnels during operation large pump chambers were built under the deepest part of the tunnel. These are shown in Fig. 30, and it will be seen that it was a difficult piece of mining work, necessitating the stiffening of the tunnels by braces and ties which were put in before commencing mining.

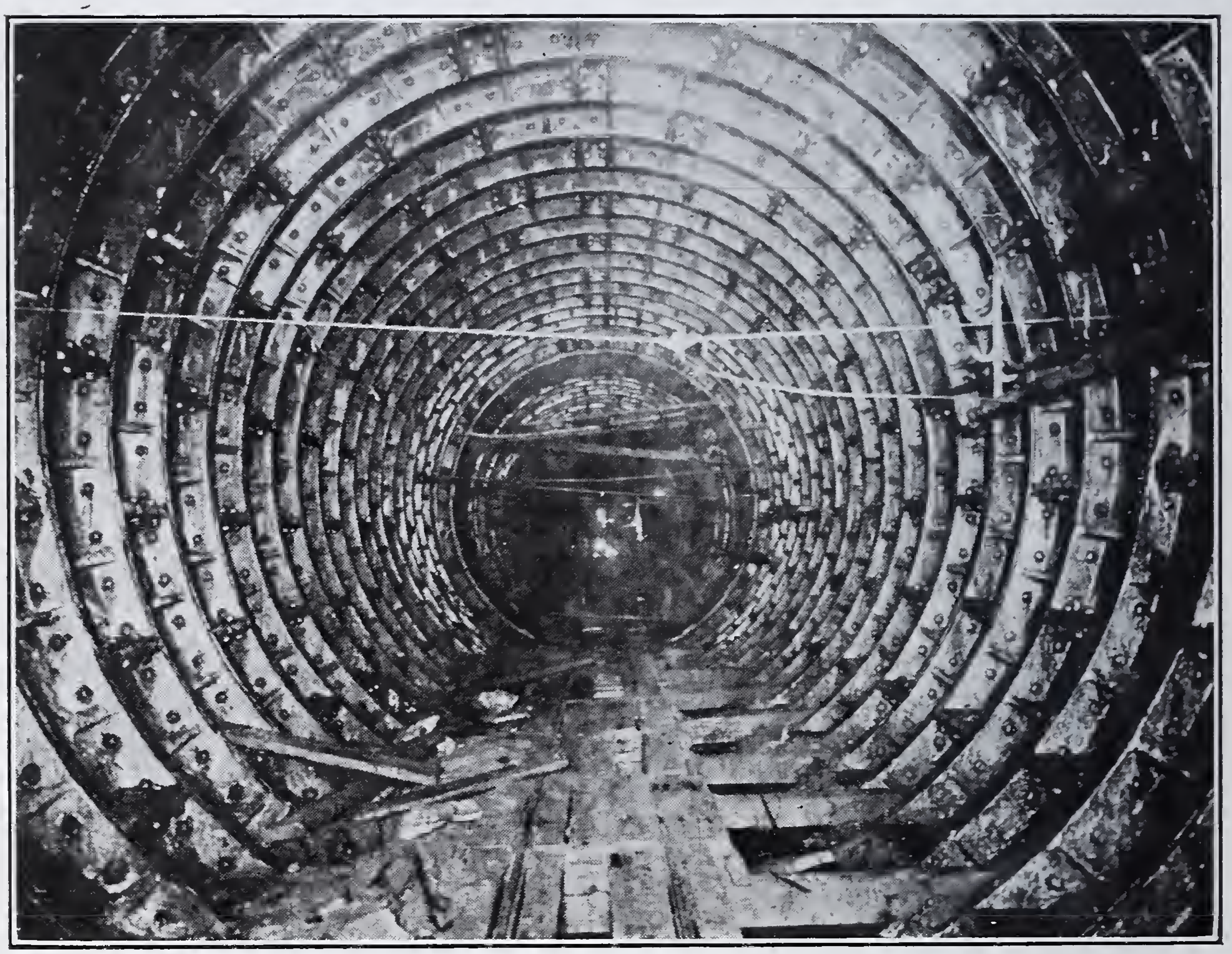


Fig. 32.

Fig. 31 shows the detail of the cast-iron lining as used in the East River tunnels, the depth of the flange being 11 inches and the width of the segment 2′ 6″ ; each segment was 6′ 66″ long, and weighed about one ton.

Fig. 32 shows the completed cast-iron lining with the shield junction in the middle distance.

Fig. 33 shows details of the concrete lining inside the iron lining.

The annular space outside the iron lining was filled with cement grout, and the concrete lining measured 2′ 6″ thick from the outside of the iron. Ducts for telephones, power cables, etc., were laid in the concrete benches, and the benches formed a gangway for the use of passengers who might get stalled in the tunnels. The track is laid on ballast.

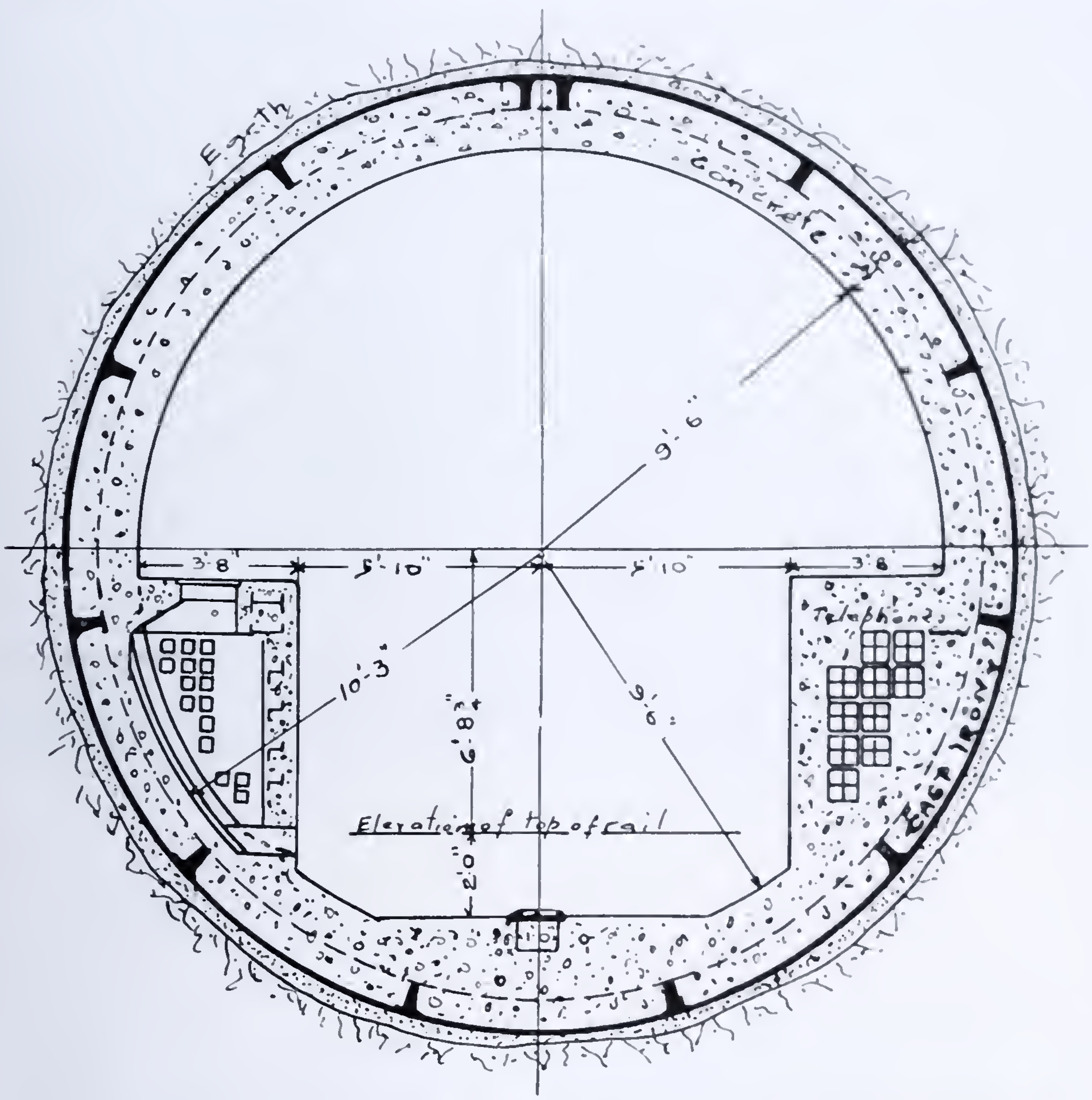


Fig. 33.—Pennsylvania Railroad East River Tunnels, Concrete Lining.

Fig. 34 shows the finished concrete. The black patches on the benches and the arch are water-leaks.

As the Long Island shields approached the Manhattan shields midway under the river, an eight-inch pipe was driven from the Manhattan shield in order to take up the line and see how closely they were going to meet, and through this pipe the first train (Fig. 35) passed through the Pennsylvania tunnels on February 14, 1908, at a speed of

160 miles per hour, as a valentine to the writer from one of the superintendents.

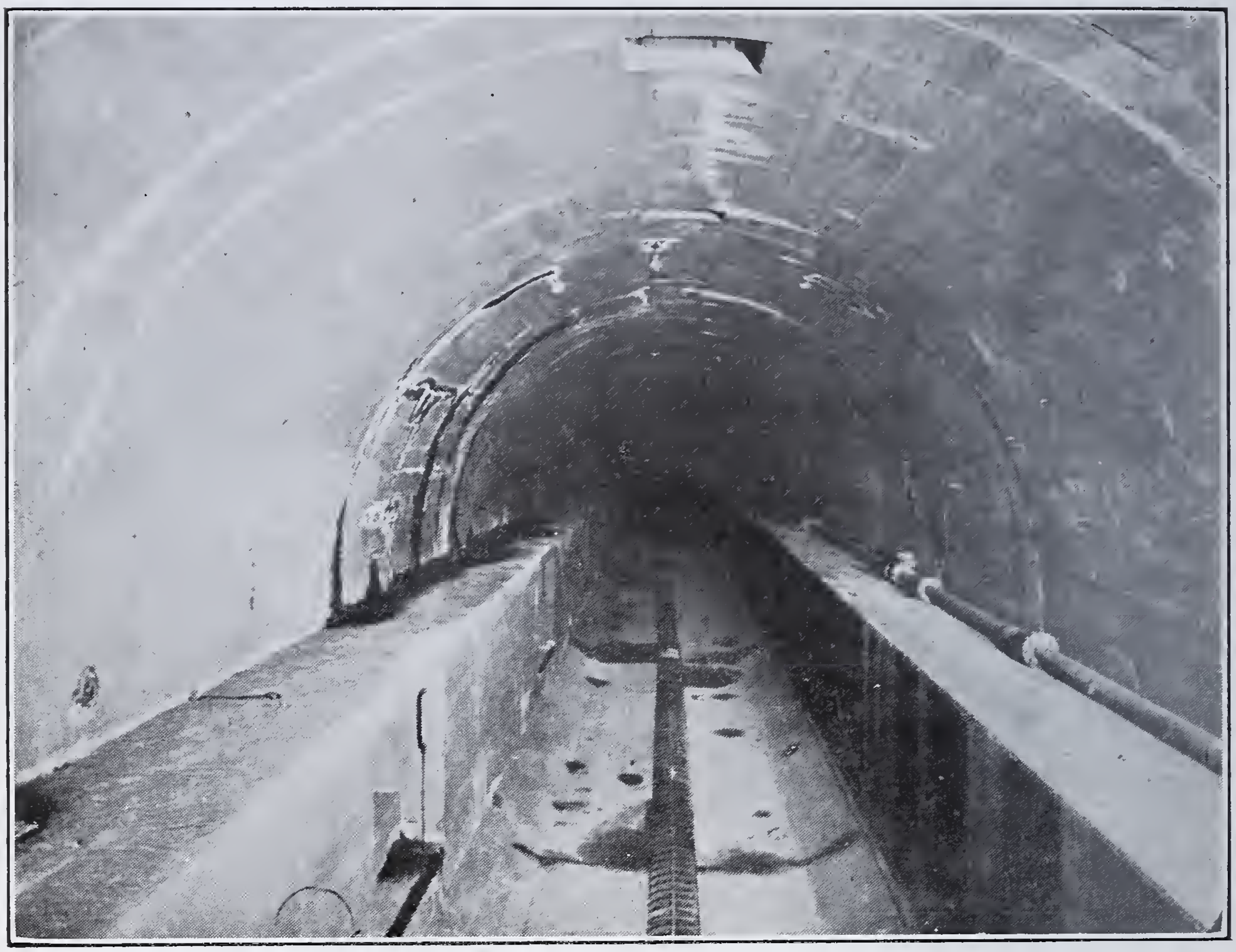


Fig. 34.

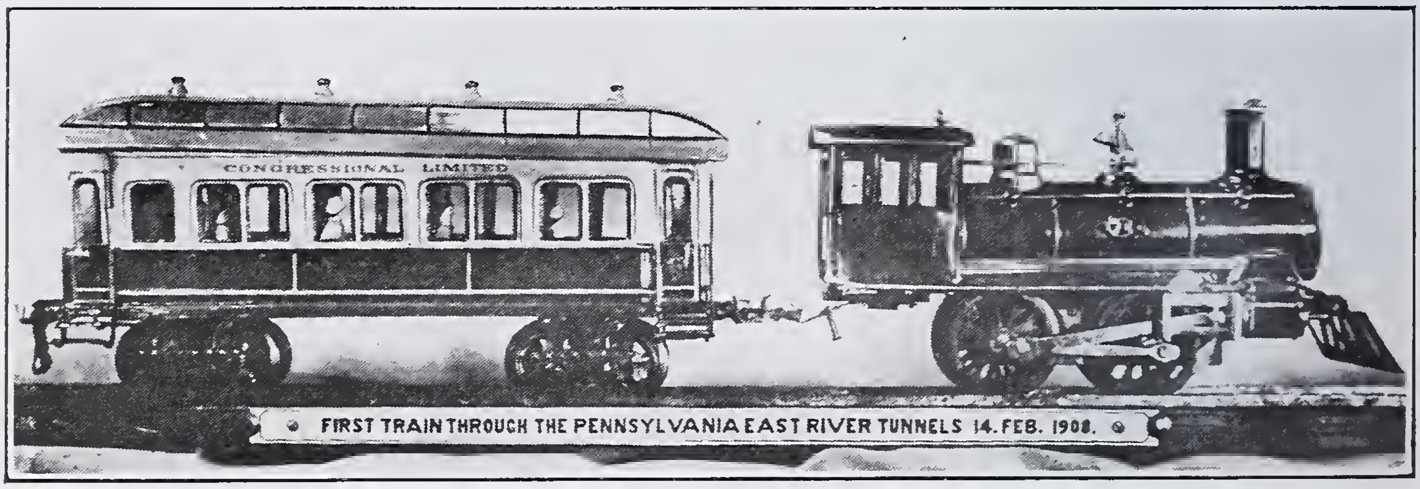


Fig. 35.

The writer is much indebted to Mr. Alfred Noble for the use of lantern slides, and to Mr. Samuel Rea, of the Pennsylvania Railroad, for his kind permission to read this paper.

DECOMPRESSION TABLE FROM FIG. 28.

Gage Pressure in Pounds.	Reduce Pressure in Three Minutes to	Total Time in Air-lock after Eight Hours' Work	Total Time in Air-lock after Three Hours' Work	Total Time in Air-lock after Two Hours' Work	Maximum Air Saturation of Body on Emerging.
27	6 lb.	9 min.	. . .	. .	25 lb.
30	7½ "	24 "	. . .	. .	25 "
32	8½ "	33 "	25 min.	. .	25 "
35	10 "	. . .	35 "	. . .	25 "
40	12½ "	. . .	48 "		25 "
42	13½ "	. . .	51 "	37 min.	25 "
45	15 "	. . .	. . .	42 "	25 "
50	17½ "	. . .	. . .	48 "	25 "

DISCUSSION.

Mr. Japp.—Mr. Quimby says I did not refer to the North River tunnels. I mentioned them, but did not say a great deal about them, as I said at the beginning that I wished to talk about work which I was intimately acquainted with, and not being employed on the North River tunnels, I feel I am not qualified to express an opinion about them. I will say this, however, that they could push and build 20 feet of completed tunnel in eight hours in soft mud, or 21 times more than on the East River. The North River tunnel men assert that this was due to their superior ability, but no East River man who has seen a North River man working in the East River tunnels will admit that.

In reply to Mr. Trautwine's question as to the pressure felt in traveling through the completed tubes, I think that the train has to overcome the momentum of the air which has to be set in motion by the train entering the tunnel, and the pressure is very noticeable on the ear-drums, especially if the train comes down the grade rapidly before entering the portal, and as soon as you pass the flash of light which indicates the Long Island City shaft, you again feel the pressure on your ear-drums, which is due to the speed of the train overcoming the momentum of the stationary air and pushing it ahead.

Mr. Swaab asked how far we drove the shield ahead of the point where grouting was going on. In all soft or mixed face we tried to keep the grout up to the face, and accomplished this by using lime grout, which had to be imported from England. We tried to have it made here, but we could not get the special quality of quick setting which was so important in the event of a "blow." This lime was mixed with water in grouting pans and forced up through holes drilled in the skin of the shield. The effect of lime grout on a "blow" being generally very marked—so much so that at one moment a tunnel required three compressors delivering 15,000 cubic feet of air per minute, and the next minute, when the lime touched the spot, only one compressor, or 5000 cubic feet, were required. The lime grouting was carried up through the fissures in the sand by the escaping air, and clung to the sand, congealing there like wax, and finally shut up the opening.

In regard to the Portland cement grouting in rock excavation, that was carried up as close to the shield as possible without leaking out around the cutting-edge. Retaining bulkheads were built, sometimes of brick and sometimes of bags.

At East Avenue the grout retaining bulkheads were built of rubble in cement mortar about every 100 feet apart.

In removing the shields after they met the electric arc was used for cutting out the steel bulkheads, floors, and vertical girders of the shields—possibly oxyacetylene would have been better.

The air-tight bulkheads supporting the air-locks were made of concrete placed inside the bosom of the cast-iron lining, and embracing the flanges for 10 feet, taking in 4 rings. They were removed by drilling and wedging.

PAPER NO. 1110.

SOME RECENT IMPROVEMENTS IN STREET PAVEMENTS.

G. W. TILLSON.
(Visitor.)

Read April 6, 1912.

THE subject of street pavements is one which has been considered for many years—in fact, I may say many centuries. Still there is something yet to learn, and it seems to us who have been studying the matter in detail during more recent years, that there is still more to learn than even we have learned during the many years that we have been paving streets.

The first pavements, as was natural, were made of rough, large, unformed stones, simply to make a footing, and these were gradually improved in size and shape so that in a few years they were better,—better made and better laid,—and as time progressed were changed to the present oblong block that we have now. The oblong block was replaced to a certain extent with asphalt, wood, and brick, until, at the present time, we have four standard kinds of pavement in use, namely:

Bituminous pavements, consisting of sheet asphalt, asphalt block, and the bithulithic.

Stone pavements consist principally of granite and the harder sandstones.

Wood and brick.

Now that we have come to these pavements gradually and by evolution, we must not think it was a short and easy task, for the advance has been made through a long line of experiments with asphalt, brick, coal-tar, cement, iron, iron-slag, india-rubber, shells, stone, leather, and even glass and hay.

The earliest pavements that this generation, or perhaps any generation, has had the opportunity to look upon have been seen in recent years, when the excavations made on the different streets of Pompeii have uncovered evidence of their existence.

The older cities, such cities as are modern today, as Paris, London, and Berlin, did not have any pavements until they were quite large. Paris had its first pavement in the twelfth century, when the city had about 200,000 people, and London had its first pavement about two centuries later, when the city had a population of, approximately, 150,000. It may seem strange, when modern cities of a population of 5000 consider themselves behind the times not to have well-paved streets, that none of the cities I have mentioned had paved streets until they became so large. In those days they did not need pavements as we have them now. Heavy carriages for the transportation of commodities were unknown in the time of Queen Elizabeth, and only about 400 carts were allowed on the streets of London. About a century later pack trains were starting from London into the interior for the transportation of merchandise. Even in 1650 Paris had only three carriages, and they were used by royalty. So these old pavements were laid with an entirely different idea from those that are laid today. Nevertheless, there is some similarity between the old pavements and the modern ones.

The ancient streets of Pompeii were all laid with large stone in the middle of the roadway at each end of the street, and although the streets show wear, it is not from the wear of carriages. The streets were narrow and the stones were probably placed there as stepping-stones. Within the last week or so there has been found a street with large pillars across the end, which would seem to prevent even such conveyances as sedan chairs from passing.

When the Romans went from Italy to Africa, on that famous trip to destroy Carthage, they found an almost perfect system of roads, something which was almost entirely unknown to them, but duly appreciated by them for the mobilization of their armies. When they got back to their own country they started to build good roads, and wherever they went they did the same thing, especially on journeys of invasion, and in that respect we are indebted to the Romans of those days, for many of the old Roman roads are still in evidence in different parts of the world.

In New Orleans, La., there is a street where the stones are about 18 inches long and about 12 inches wide. These pavements have been in use for about eighty years, and it is claimed that after the stones have worn down on one side, they can be turned over and

used on the other side. Where the stones are kept in good condition they make a good surface.

The pavements considered standard today are bituminous, wood, brick, and stone. Asphalt is a cementing material. I am not going into the technical part of this, because you would be here a week if any one attempted to go into that. But the asphalt binds the sand together in the same way that Portland cement binds the stone to make a cement mortar.

The first asphalt pavements laid in this country were laid in about 1871, although the first ones of any magnitude were laid in 1877 on Pennsylvania Avenue in Washington. The first mixture was about 10 per cent. of asphalt, or rather of bitumen, and 10 per cent. of stone-dust, which was put in to make the mixture dense, so that it would not absorb water, and so that it would give extra wear, and 80 per cent. sand. The surface was 2 inches thick and was laid on what was called a cushion coat. This cushion coat was laid ½ inch thick on the concrete and then rolled, and the 2-inch asphalt surface laid upon that. It was found that the material laid as hot as it was—at a temperature of probably 250° F.—when the concrete was damp, would cause steam to arise and make bubbles under the cushion's coat, and raise it up from the concrete, so that after the paving was laid a certain length of time it would slide on the concrete; then, with the cushion coat rolled down so smooth and hard, it was difficult to make the wearing surface stick.

So it was decided to lay what was known as a binder coat, formed of stone ranging from 1 inch down to ¼ inch in diameter, mixed with about 7 per cent. asphalt. The idea was not to have a dense mixture to fill the voids of the stone, but to leave them open, so that when the wearing surface was laid upon it, it would, when rolled, fill the voids in the stone. After asphalt paving had been laid in this way on streets of heavy traffic it was found that the traffic, which sometimes is as much as 1200 or 1500 pounds per inch on the tire, would drive the wearing surface down into the voids of the binder farther than the roller, and consequently make the pavement uneven and cause the water to collect and introduce undue wear. In order to get away from that trouble within the last few years there has been used what is known as the "close binder." That is, the asphalt as it is mixed with the broken stone is also mixed with sand and stone-dust, so that there is obtained a layer of the binder that has practically a good wearing surface, but not quite so good as the asphalt;

it is one that will not wear down nor compress unduly under heavy traffic.

Another change which has been proposed, although used only to a very small extent,—in fact, I have not seen it anywhere myself,—is to have the concrete finished with a hard, smooth surface, practically like the cement sidewalks, except that it should have no polished surface; then upon this concrete will be painted the asphalt, of a thick mixture, and after it is allowed to cool the asphalt wearing surface laid directly upon that. The theory is that the "paint" coat will take a firm hold upon the concrete, and the wearing surface will take a firm hold upon the paint coat, and after the surface is complete there will be one that has no inherent weakness after it has once a firm hold upon the concrete. This, however, is in an experimental stage at the present time. It requires the concrete to be laid almost perfectly. If it is loose on top, the paint coat will not hold, and the concrete must be absolutely dry when the paint coat is applied. If the paint coat will take a firm hold upon the concrete, I see no reason why it should not be successful.

Asphalt is, of course, smooth and slippery. It has been laid in the shape of asphalted blocks. The first ones were laid 5 inches deep and 4 inches wide. This, of course, was very expensive, laying 4-inch material instead of 3-inch by the sheet method, and the asphalt blocks made at a central plant had to be conveyed entire to the street where they had to be used, and this made the transportation scheme expensive. In almost every locality sand can be found within a reasonable distance from the plant, so that the transportation cost, as in the case of concrete, will be small, and it will be necessary to pay for extreme transportation for only 10 per cent. of the pavement. In order to reduce the cost the blocks have been reduced from 5 inches to 4 inches and then to 3 inches and even 2 inches. The 2-inch blocks have been laid for two or three years in non-residential streets. Theoretically, the asphalt blocks should wear much longer than the sheet asphalt, because they have an absolutely uniform pressure and can stand a much heavier pressure than can be exerted by any roller on the street. As a matter of fact, I do not think they are doing all that we can theoretically expect. In their use, however, you do not require a plant for making repairs; any ordinary repairer can do that at any time.

Some ten years ago a gentleman who was connected with the asphalt industry conceived the idea of improving macadam pavements by adding coal-tar to the stone, and finally he elaborated his

work to such an extent that he mixed the coal-tar with the stone, which was graduated to such a degree that the voids were reduced to about 20 per cent., and a pavement evolved which was called the "bithulithic" pavement, and which is considered standard at the present time. The bituminous material in this pavement is generally coal-tar, although asphalt is sometimes used. It has one advantage over asphalt, that, being made of coarse stone, ranging from 1½ inches downward, it can be laid on steeper grades than finer mixtures, as it is not slippery. In Pawtucket, R. I., it is said that it has been successfully used on grades of 8 to 12 per cent.

In the central West, where stone is scarce and where stone, asphalt, or anything of that nature, has to be transported long distances, all such materials must be expensive. However, about thirty years ago some one in Wheeling, W. Va., entertained the idea of laying pavements of brick, which was ridiculed, especially by the eastern people, but they did not know the possibilities of the clay in Ohio, Indiana, and Illinois. The experience of the brick people has produced a standard pavement which is used a great deal in the central West. The brick people have also evolved a testing machine which will test quite accurately the wearing qualities of the brick, so that tests can be applied to the bricks before they are used, and it will be known almost positively whether the brick will or will not prove satisfactory in the pavement. Brick is also used as a material in paving the roads in the central West. It is said that several counties have hundreds of miles of this road.

The evolution of the brick pavement seems to me to show, almost as clearly as anything can, the adaptability of this country to its needs; in fact, it is almost impossible to bring up a problem of any kind which we are not able to meet. It did seem at one time that it would be impossible to produce a pavement which would be successful in the middle West at any cost, but the manufacture of the paving brick has solved this question admirably. Brick paving is laid on a concrete foundation, as a general rule. The National Paving Brick Manufacturers' Association contend very strongly that brick pavement should always be laid on a 2-inch cushion of sand placed on the concrete. Most engineers, however, differ from this, and think that a 1½-inch or even a 1-inch cushion is sufficient if the concrete is smooth. Some of the early pavements were laid with so-called second-class brick as a foundation, placed flat, covered with sand, and the wearing brick laid upon the sand

cushion. This was done for the sake of economy, although at the present time the National Brick Manufacturers' Association advocate a method something like this, excepting that they use the largest size bricks and grout the joints, claiming this makes a better foundation than the concrete.

The principal consideration is the filler for the joints. The other fillers used are bituminous material and sand. The objection to the sand is that it does not protect the edges of the brick. The bituminous filler is better, as it prevents the pavement from being a continuous whole, and prevents it from giving forth a rumbling sound, such as one hears when a loaded truck is driven over a brick pavement when the joints are filled with cement. There is no question, however, in my mind that if one gets a good cement grout joint one will get a better wearing pavement than in any other way, but there is an objection to its being one slab, as you might say, and also the difficulty of opening it up and repairing in case of making cuts.

"Hill bricks," with a groove on one side, are also made for use on streets where the grade is steep. There has been practically no radical change in the construction of brick pavements since they have been first laid, because the evolution of this pavement has been simple and gradual, rather than positive and at random.

I think the best paving bricks are made in Indiana. We had some made on the Hudson River, but they were not satisfactory. There seems to be something about the Ohio, Illinois, and Indiana brick that makes it particularly adapted for paving. You see you do not simply want a hard brick, but one that will be tough, and it is particularly hard to get—a brick having the hardness and toughness, without brittleness.

The brick pavement laid with the cement joint has a tendency to swell up and buckle. Under present methods of construction it does not occur as much as it used to, as the pavement is provided with expansion joints filled with bituminous material which takes up the expansion to a certain degree.

It is difficult to see why any material which has been heated up to 1800° or 2000° F. should cause trouble by expansion on a street surface, but, as a matter of fact, there have been cases where pavements have exploded with a loud noise. I know of two blocks of pavement that were laid several years ago, where there was a rumbling noise like that made by driving over a wooden bridge. We took some of

it up and could find no cavities, and although a space was cut out along the curb, no relief was obtained; it seemed as if there was one immense brick plank lying on top of the sand. After it had been down two years, it was taken up and relaid with asphalt joints.

There has probably been less change in the construction of stone pavements since they first began to be used in the oblong form, although they have probably required it more than any other pavement. Those of us who have lived in this country and have never had an opportunity of looking at the paving abroad have heard that the stone pavements of Europe are much superior to those of this country. I do not doubt that this is true. In Europe the blocks are made better, smaller, and more even, and in many cases they are dressed on the tops and sides. In this country the great item of cost is labor. Our granite-cutters are paid by the piece. They make perhaps $5.00 a day, whereas the European cutters make only about $1.50, and are content with that. So in making any material change in the block you add materially to the cost of the paving, and before we get our streets in the condition they should be, we must make this change and pay what is necessary to get it. Such pavements as we have been laying cost about $3.30 per square yard, including the foundation. The specifications say that the blocks shall be 8 to 12 inches long, from 3½ to 4 inches wide, and from 7 to 8 inches deep, and should be laid with a ¾-inch joint filled with gravel, which shall range from ¼ inch up to the size that would go in the joint, and the spaces between the gravel shall be filled with a preparation made of coal-tar, pitch, or asphalt.

Last year, in order to get an idea of the European specifications, the Bureau of Paving of Manhattan advertised for granite blocks on Lafayette Street, the blocks to be made according to the Liverpool specifications, and also that a certain portion of them should be blocks of the character used in Liverpool. There were three sections in this line of paving: one required 4-inch cubes imported from England or Scotland; another 4-inch blocks of American granite; and another smaller blocks, made according to Liverpool specifications, 6 x 4 inches and 6 inches deep. The lowest bid received for that pavement was $4.50 per square yard, not including foundation; with the foundation it would have cost about $5.30 or $5.40 per square yard.

Two years ago the engineers of the different boroughs of New York and some of the engineers of the neighboring cities met the granite producers to see how good a block could be produced at a reasonable

price. After a long conference the best that the producers would agree to, without considering what the cost would be, was a block 7 to 12 inches long, 3½ to 4 inches wide, and 5 inches deep, but dressed better than before.

The old deep blocks were designed for a foundation of sand, and it was thought, by reducing the depth to 5 inches, that a block would be obtained which would lay with a half-inch joint and have no depression on the head greater than ⅜ inch; but the producers of granite blocks felt unable to furnish such a block within a reasonable time and in large quantities, so they said, "Give us time! Let us educate the paving cutters." The producers also stated that twenty years ago, when the use of asphalt came into vogue, granite then was not used to so great an extent; most of the granite-cutters, who were mainly old countrymen, went home, and there are no workmen here.

The city of Newark laid two or three pavements under the above specifications, and great difficulty was experienced in getting the blocks on time. In later years other cities have done some work under the same specifications, and it has been easier to obtain the blocks.

With a smaller stone and smaller joints you cannot use the coarse gravel, but with the ½-inch joint we use a gravel that will fill the joints and the pitch and asphalt. In some cities a Portland cement filling is used. The grout is mixed 1:1, applied rather thin, and broomed into the joints after the blocks have been rammed. Additional brooming is done until the joints are filled. The Newark specifications required the surface to be swept until the paving is absolutely smooth on top,—made so by the grouting,—and in order to do this the street must be kept free from traffic for seven days.

Another granite paving is on a New York avenue from Ninth to Twenty-third Street. The difference in the specifications there, however, was that the blocks should have only ¼-inch depression, and the joints should be ⅜ inch instead of ½ inch. The idea with the smooth block was to get as smooth a paving as was possible. You cannot get a smooth paving without a smooth joint. The paving is a great deal smoother than it looks—it is just as smooth as asphalt, but the inequalities in the blocks are there, and a heavy tire will rise on top of the bunches. The use of the pitch joint is to reduce the noise, and we think that, by having this pitch joint, the sound

is muffled, so that you do not get quite as sharp a sound as if the blocks touched one another.

That street had an asphalt paving on it for over five years, and there was much objecting when it was found that stone was to be laid instead. Of course, granite is the pavement to be used when economy only is considered.

A street laid with granite blocks and the joints filled with cement grout is, so far as use is concerned, as smooth as an asphalt pavement. I examined one two or three days ago and was rather surprised to find that, at intervals of perhaps every 100 feet, there were cracks along the street caused by cold weather. I do not think that, so far as wear is concerned, they will do any harm. It is possibly a stretch of 2000 feet, and there were absolutely no joints for it to slip.

Scoria block paving, as laid in Amsterdam, is made of iron slag run into molds while it is hot and then allowed to cool. These blocks were laid on a heavy-traffic street in Brooklyn, about 24 or 26 feet wide, where a Canton brick pavement had lasted for ten years under heavy traffic. The Scoria pavement lasted six years.

The most recent paving we have is the wood block as it is laid today. The first wood blocks laid in this country were laid in the forties in Philadelphia, New York, and Boston. They were made of any kind of wood, and laid in almost any kind of way, and correspondingly lasted only a short time. Then little or nothing was heard of wood paving for about twenty years; it is singular that paving fads seem to run in cycles of about twenty years, for about twenty years later there came up the Nicholson block, which was a creosoted pine block laid on a plank foundation with concrete in between; it made a first-class pavement for a year or two, but soon the blocks began to decay irregularly, and the result was decidedly bad.

In practice, this pavement cost as high as \$4 to \$5 a square yard, and when asphalt began to come in, it was sometimes laid on top of this wood-block paving. Only last year we took up an asphalt pavement that had as a foundation wood that was laid over twenty-five years ago.

Still, twenty years afterward there came up the cedar block craze through the West, and it was much in evidence where real estate booms were on and ambitious towns wanted a pavement quickly. Chicago at one time had 700 miles of it. It cost 70 or 80 cents a square yard, and lasted only four or five years. About twenty years

after that some people in Des Moines thought that if they laid good pavements of wood in the old country they could do the same thing here, and they tried treating the wood blocks with creosote. The first blocks treated had an uncertain quality of oil and an uncertain quality of wood, but the general results were good. This process was followed by treating the blocks with a creosote-resin solution, made of equal parts of creosote oil and resin. There were no requirements in the early specifications as to the character of the oil, and I think the first pavements of that character under general specifications open to the public were laid in Brooklyn in 1903.

A street was paved with wood in 1902, the city prepared the foundation, and the contractor furnished the blocks and laid them for nothing, as an illustration of what the pavement was. The pavement today is in practically as good condition as when it was first laid

In preparing our specifications the question was put up to me, "How do you know our pavement is going to have this treatment?" We did not wish to have an inspector to inspect the blocks, and decided to have an absorption test and a specific gravity test for the block as follows: The block was dried for twenty-four hours at a temperature of 120° F.; it then should not absorb more than 3 per cent. of water after being immersed in water for twenty-four hours, and it was also provided that all blocks should sink when put in water. We let quite a number of contracts under those specifications, with no expansion joints, and have had almost no trouble. We have some streets that have been down some seven or eight years, and have had absolutely no trouble with them. I stated that the composition used was creosote oil and resin. We did not want to make a specification that would be an absolute monopoly, and although we did not think that more than one man would bid, we made the specification "creosote and resin, or some other suitable material." However, a new contractor turned up as the lowest bidder, and he did not use resin, and my chemist had several weeks wrestling with the analyses and the oils before he could determine if the material was suitable water-proofing material; as near as he could tell it was pitch, but we finally decided it was a suitable water-proofing material and accepted the contract and the blocks were shipped.

Another point is that wooden blocks require a certain amount of

traffic to keep the blocks matted down and to prevent any moisture getting into the blocks and softening them up.

There are quite a number of moot points in the manufacture of wood-block pavement, but the principal question is the character of the wood; then the cushion for the blocks, and the character and quantity of treatment. Now I think there is no question that the best material for the pavement itself is hard pine, long-leaf yellow pine, although that perhaps is not necessary in a residential street. It is hardly possible for a street to wear out, such as we have in Brooklyn, but it must have a certain amount of traffic to keep it down.

The only other material that we have used to any extent is the black gum. The Government is making an elaborate set of experiments to determine not only what is the best wood, but what are some of the cheaper woods that can be used for paving purposes and give satisfactory results, as the hard pine is becoming dearer and dearer, as well as the cost of laying. I think it absolutely safe to use the hard pine.

And now it comes to the question of the cushion: the original pavements laid in Brooklyn had a cushion of cement mortar of 1:4 mixed as dry as it could be. If it was too soft, the heavy blocks would settle in it, and an even surface could not be obtained. We did, however, get an even surface with the wood blocks laid on that cushion. I think the cement cushion is better than the sand cushion.

Then there is also the question of the filling in the joints, which sometimes are filled with sand, sometimes with cement grout, and sometimes with pitch. When there is any traffic in the Brooklyn streets you hardly see any joint at all. We want fine sand so that the joints will be filled, and it seems to me that with this pavement you get a satisfactory pavement. I do not know but the benefit of not bulging in wet weather is due to having the sand joint. Some people of the West are using the bituminous filler, but, as often happens, the blocks bleed, and the pitch in the joints simply adds to the trouble and makes the nuisance greater. If a bituminous filler is used, it acts as an expansion joint, and there should not be so much bulging with the bituminous filler joint as with the other fillers.

The treatment of the block itself is an undecided question so far as experience is concerned. The question is, shall the block be treated with a plain creosote oil, oil obtained from water-gas tar, or a creosote oil to which enough pitch has been added to give it a

specific gravity of 1.10. The specific gravity of ordinary creosote oil will run from 1.03 to 1.06. The requirements are to preserve the block from decay and prevent its deformation on the street, which if fulfilled should give a pavement that will last as long as the filler that is put into it. In addition to preserving the blocks from decay they must be kept in place and must not absorb water enough to expand in wet weather, or lose moisture enough in dry weather to become loose. The only reason that I prefer the creosote oil is that it will preserve its characteristics longer than the light gravity oils, and it will prevent the water from swelling or shrinking in hot, wet, or dry weather. I prefer a 1.10 oil. The oil is introduced under a vacuum.

I think the wood-block pavement is more slippery than any, and practically I think that is the only thing you can say against it. Of course, in dry weather, if it is absolutely dry, there is no slipping on it, but if there is a little dirt on it when the pavement is damp, a slimy, slippery surface is produced.

The cost of that paving is $3.20 to $3.50—almost the same as granite laid with the same kind of base and under a five-year guarantee.

Most of the European blocks are made of soft wood. I have seen blocks which were originally 6 inches worn down to 4 inches. When a truck runs over that it will crush the gravel into the soft blocks, which it might not do with hard pine.

TABLE SHOWING PROPERTIES OF A PERFECT PAVEMENT AND PERCENTAGES ASSIGNED TO THE DIFFERENT STANDARD PAVEMENTS.

	Per Cent.	Granite.	Wood.	Asphalt.	Brick.
1. Cheapness	14	8	8	14	11
2. Durability	21	21	16	15	16
3. Ease of cleaning	15	10	14	14	15
4. Load resistance to traffic	15	13	14	12	15
5. Non-slipperiness	7	7	4	5	6
6. Ease of maintenance	10	10	8	6	6
7. Favorableness to travel	5	2	5	4	3
8. Sanitariness	13	9	13	12	10
Total	100	80	82	82	82
Less cheapness	...	72	74	68	71

Bitulithic is assumed to be about the same as asphalt.

DISCUSSION

Solomon Swaab: Is it not fair to assume that if you eliminate the horses and use the motor the figures will change entirely?

A. Yes, the whole problem changes then.

TABLE

Material.	First Cost. Sq. Yd.	Expense per Year. First Period.	Average Expense per Yard per Year. Fifty Years.
Granite	3.50	0.294	0.270
Wood	3.50	0.308	0.274
Asphalt	2.00	0.208	0.164
Brick	2.50	0.224	0.199

In Brooklyn we have kept accurate costs from 1902, and we have a ten-year curve showing a very uniform cost. Asphalt is not a positive substance that you can tell how it is going to act. Paving fifteen years old cost 9 cents per yard per year. If you strike an average, there would not be so much difference between the Buffalo pavement and the cost of the Brooklyn pavement. In Buffalo there are records of repairs up to twenty years out of guarantee. They say there, however, that they have not had enough money to keep their pavements in proper repair, and that if they had a little more money, it would have cost perhaps 10 to 15 per cent. more than is shown.

A diagram received from the city of Washington shows a remarkable condition. The cost runs up to 2 per cent. for the first year under guarantee, being practically the same as Buffalo and Brooklyn; it then runs along up to 3, 4, and 5 until it gets to the nineteenth year under guarantee, and when the pavement is about twenty-four years old, to about 6¼ cents, which is the highest cost; from the nineteenth year on it begins to drop. The pavements out of guarantee twenty-nine years cost 2 cents a yard for repairs. It is a remarkable condition, but then Washington is a remarkable city—abnormal, I may say, in that respect. The streets are wide, the traffic is light, and the traffic is also fairly equable, and there is enough money to keep the streets in repair.

Mr. Swaab: Where you have 6, 7, 8, and 9 cents for maintenance, does that mean that you have maintained that pavement in its original form? Does it not depend upon what standard you use?

A. Absolutely; but in Brooklyn we have kept these pavements in absolutely good condition. In Buffalo they make the explanation that they might have spent 10 to 15 per cent. more. In Washington the pavements have been kept in good condition.

I have a scheme for determining at what time it was proper to relay an asphalt paving:

Let N = Life of proposed paving.
C = Cost per square yard.
I = Rate of interest.
R = Estimated cost of repairing if distributed over entire life.
A = Sinking fund to be paid each year to equal C at the end of N years.

X+C I+R/N = the annual expense of new paving.

If this annual expense is more than it is costing to keep the pavement in repair, it is not policy to relay it. Perhaps, by spending 15 cents a yard on a pavement this year, it might be put in such condition that next year it would be necessary to spend only five cents.

It seems to me that this is a scientific way to determine when to relay pavements; that is, for a sheet pavement. Granite cannot be determined in the same way.

Karri wood is used a little in New York, on Twenty-second Street near Fifth Avenue. It did not give satisfaction. Hard-wood pavements require almost no repairs in the first five years as compared with the soft woods.

Wm. Easby, Jr.—Are there any standard surface mixtures in use; that is, standards with reference to the grading of sand, amount of filler and bitumen used? Also, has it been possible to adhere to such standards?

A. We have been figuring on that to quite an extent this past winter. The real thing in asphalt is to have the right kind of bitumen; that is the thing which is absolutely necessary; then the grading of the sand is important, and also the filler, as you suggest. There is much questioning among engineers as to the grading of the sand. There are two schools—one believes in the fine mixture, and the other, in the coarser. I believe in the finer sand myself, and the more bitumen you can carry, the better your pavement will be and the longer it will last. For a heavy traffic street I think you should have from 11 to 11.5 per cent. of bitumen. I have forgotten exactly what the grading of the sand is, but I favor the use of that which will all pass a 10-mesh sieve. It is almost impossible to find a sand that will give a perfect grading, and the contractors, as a rule, use the best they can get in any locality. They mix it to get it right.

The construction of an asphalt street is a very difficult problem, and it is a strange fact that when the asphalt companies keep an accurate record, mechanically and chemically, of how they lay all their pavements, and then duplicate the best as nearly as possible, they do not get the same results.

The first asphalt pavement I had charge of was in Omaha, Nebraska, in 1882 and 1883. Omaha is about as difficult a place in which to maintain an asphalt pavement in as any in the country, as the natural sand grading there is bad. Omaha's summer temperature is from 140° in the sun to about 110° in the shade, and in winter I have seen it 30° below. However, that pavement referred to above was down for twenty-five years; it was laid by rule-of-thumb, and it was a better pavement than many laid today by scientific principles.

A few rules were used in Omaha thirty years ago. They are doing better now; but what I mean is that it is very hard to get the mixture just right. Asphalt is an artificial mixture and sometimes gets too hot; if the sand or the asphalt gets too hot, nobody knows anything about it, because the man in charge of the work knows enough, usually, to keep quiet. If the asphalt is good, and is laid with a good grade of sand under good conditions, it should not fail.

Q. Is there not less chance of burning the asphalt now with the steam coil?

A. Yes; and if you use the oil fuel, you can easily maintain the heat as desired.

W. H. Fulweiler.—With reference to the treatment of the wood block: you spoke of the proper kind of oil to be used. Is there any accelerated test by which you could determine to a reasonable degree the uses to which this oil could be put; that is, as to the complexity of the oil itself. Would you have to wait twenty years to be able to tell whether the oil was suitable or not?

A. The whole thing is complex. I have made certain tests by taking oil and subjecting it to a high temperature for a fifty- or sixty-day test, and getting the difference in evaporation. If your oil evaporates very quickly, it is going to fail in a short time and will not prevent the blocks from swelling.

Mr. Fulweiler.—Then a low line of evaporation would be a valuable constituent in an oil filling?

A. I think it would.

Q. What temperature would you use?

A. I would make two or three tests, starting in with what would approximate a normal temperature, say from 120°, which you would get in the sun, then another test at possibly 250°, and compare results.

Q. You do not believe, then, that the distillation would represent the loss in evaporation?

A. It would, to a certain extent; but, of course, those distillation tests are made at certain high temperatures.

Mr. Fulweiler.—I am glad to hear you say that, because some people say that you ought to be able to tell exactly what any oil would do by distillation tests. Has the absence of free carbon any effect at all on the quality of the oil?

A. It will have something to do with the penetration qualities of the oil. If you have too much free carbon, you prevent the oil going into the block, but if you have only enough to allow free penetration, it will keep the water out, and if you keep the water out, I think you will prevent the decaying of the block.

Paper No. 1111.

THE ENGINEER IN HIS RELATIONS TO THE CITY PLAN.

NELSON P. LEWIS

(Visitor.)

Read May 4, 1912.

A great deal lately has been said about what is called city planning. Everything relating to municipal affairs has been very fully discussed, including accounting, budget making, 100 per cent. efficiency, commission government, and many other things which might be classified as ideas or idiosyncrasies, as facts or fancies. City planning has been the subject of local, State, national, and international conferences, conventions, and exhibitions, has been discussed in lectures, newspapers, periodicals, and books, and one quarterly publication is devoted exclusively to this subject. Such evidences of wide-spread interest could not well have been manufactured by those having some selfish interest to promote, but it seems quite clear that the public is becoming greatly interested in the subject. It cannot, therefore, be dismissed as a fad or as a matter that appeals only to theorists, but we must recognize it as something real and vital to the proper growth of our cities. In this paper an effort will be made to discuss the following questions:

1. What does city planning mean?
2. What are its economic advantages?
3. What progress has been made in city planning in this and other countries?
4. Who should be responsible for the city plan?
5. What general principles should govern city planning?

First, then—what is it? It is simply the exercise of such foresight as will promote the orderly and sightly development of a city and its environs along rational lines, with proper regard for the health and convenience of the citizens and for the commercial and industrial advancement of the community. It does not mean what has been so often called the "city beautiful." It does not mean or even include municipal art, nor does it, in the author's opinion, include the architecture of public or semi-public buildings.

A city planned in accordance with the principles laid down in the above definition will surely become beautiful; it will lend itself to artistic treatment (not adornment by municipal art, for it is difficult to explain in what respect "municipal" art differs from any other kind of art); it will provide adequate sites for public and semi-public buildings, which can be availed of by the architect when the time comes without the expense of rearranging the street system to give them a proper setting. To plan a city with its final artistic embellishment would be not only folly, but would be far beyond the capacity of any one man or group of men in any one generation. To attempt to designate the specific sites for future public buildings with a special regard to the size, shape, and design which those making the plan deemed to be most suitable would evidence an arrogance and self-complacency which would render one unfit for the task he has undertaken.

Reverting to our definition, the planning should include not only the city, but its environs—that is, it should bear some relation to the neighboring cities and the rural and small urban districts which are within easy reach. Every city is supported, to a large degree, by the country behind or about it. The idea that every effort should be made to confine its working population as far as possible within the red lines forming its boundaries is a fallacy having its origin in the selfishness of those who wish to maintain realty values within the city at as high a figure as possible. The object should be to reduce to a minimum the resistance to both intraurban and interurban traffic. This applies not only to ordinary street traffic, whether by vehicles or surface railways, but to steam and electrically operated railroads for the transportation of passengers and freight. The idea that railways are an evil which must be tolerated, but that they should be kept out of sight and should be compelled to carry on their business almost surreptitiously, is a grave mistake. A city cannot live, much less grow, without them. A city plan must, therefore, provide not only direct and ample thoroughfares for vehicular traffic and routes for the transportation of passengers to and from their homes within the city, but it must take into account the vital necessity of railway lines and terminals for the economic and expeditious handling of passengers and freight in such a manner as to reduce, so far as possible, the time and expense of transportation to and from home, office, shop, or factory, from and to points outside the city.

Thoroughfares should be both radial and circumferential. In

every great city there is always one center of the first importance with a number of minor centers. The great radial thoroughfares will necessarily converge at the principal center, with minor radials reaching the subordinate centers, while the circumferential thoroughfares will connect the less important centers with each other and make it possible to go from one to another or to the suburbs without passing through points or districts of traffic congestion. The plans suggested almost simultaneously by Sir Christopher Wren and Sir John Evelyn for the rebuilding of the central portion of London after the great fire of 1666 illustrate this idea, but, unfortunately, neither plan was carried out. It is also shown, by the diagrams of radial and circumferential streets included in the report of the Metropolitan Improvements Commission of Boston, which shows how many links in such a system often exist, and how relatively simple a matter it is to supply the omissions. The possession of such a system of main thoroughfares would greatly simplify the problem of providing adequate transportation facilities, which most of our cities find so difficult of solution.

Regard for the health as well as for the convenience of the citizens requires that there shall be ample provision for open spaces for recreation and amusement. In other words, that there shall be, within easy reach of every home, a park where the occupants of that home can find fresh air and out-of-door rest or play. This does not mean that the parks must necessarily be large, that they should be highly developed by the landscape architect, or that they shall be located upon most expensive property. There are many tracts of land of varying sizes which are passed over by the real estate operator as unsuitable for development, and the cost of which would be very small, but which, if secured and held, would become extremely valuable to the public as parts of the park system of the future city. Nor need they be developed for years to come. A piece of natural woodland, a creek bottom now little more than a swamp, a rocky ridge or steep slope which is unavailable for building purposes, can often, by the building of a few paths or drains, be made to serve their purpose as playgrounds at slight expense. The important thing is to secure them while they are still cheap, with the right to dispose of or convert to other uses such portions of them as may not be desirable for park purposes when the city plan is finally developed. The idea which seems to have controlled the park policy of most American cities is that parks shall be located and purchased only when the actual

need for them is developed, but meanwhile property has been converted to other uses and has been covered with improvements, the destruction of which, as well as the enhanced value of the land and the disarrangement of the street system, would make the cost of the park so great that the project has to be either abandoned or curtailed. The cost of parks secured under a more rational plan, including loss of taxes and carrying charges, would be far less than under the policy generally prevailing, while if acquired in accordance with a plan which will be outlined later, they can readily be made to carry themselves. Boston and Philadelphia have followed a more enlightened policy in this respect than have most other cities. In both these cities large areas peculiarly suited to park purposes have been acquired while the land was still inexpensive. In the first named these areas have been generally outside, and in the latter they have been within the city limits. Neither of these cities, however, appears to have made adequate provision for small or neighborhood parks.

There is one other element in our definition of a city plan, and this is fundamental, namely:

The city plan, as the expression is used in this paper, is not a map upon which are laid down with precision all the streets which will be required for its ultimate development, but it is the general plan of arterial streets and transportation lines by which the different sections of the existing and the future city will be connected with each other and with centers of population outside the city limits, the parks and open spaces, and other resorts for recreation and amusement, the existing water-front development, and the space needed for its further increase, existing public and semi-public buildings, and sites upon which those required in the future may be advantageously grouped. This is the real city plan which will control future city development, stimulating it or retarding it, as the case may be. The block dimensions and angles, the widths of minor streets, and the subdivision into a vast number of rectangular blocks of standard size, with an explanation of or an apology for every departure from that standard, do not constitute a city plan. The city plan is something bigger and broader. It is something to which the city may grow, not something to which it must be restricted or within which it must be confined as in a strait-jacket.

The economic considerations which should control the city planning are precisely those which should prevail in the design of a house, shop, railway terminal, or water-supply system, namely, adaptation to

probable increase in demand and capacity to supply that demand. If the manufactory or the railway is foreordained to failure, the less spent upon it the better. There are a few towns which were laid out during "boom" periods on lines which were fancied to be those of a future metropolis, where the broad streets are grass-grown, where the public buildings are but half occupied, and where everything speaks of a splendid ambition which resulted in grotesque failure. When a city occupying a strategic geographical position has begun a natural development which causes growing pains indicative of a misfit in its general plan, it is time to look forward to adjust the plan to new conditions and to provide for still further growth. To tear down and enlarge is very costly—especially so when there is no room for enlargement without the purchase of additional land, which has become far more valuable than when the original enterprise was begun. This is constantly being done by individuals and corporations whose domestic or business requirements make it necessary. In every case it involves a distinct loss, which may be justified by means to indulge in a luxury or by the prospect of increased profit. Cannot the city, it may be asked, instead of trying to provide for the remote future, well afford the expense of reconstruction to adapt itself to its growing needs, especially when it has the power, through its ability to levy taxes and assessments, to impose the cost of necessary changes upon the property which will be chiefly benefited? No expense involving the destruction of property can be justified if it can be avoided by the exercise of reasonable foresight, and the taxing power of the city should not be used unnecessarily. The requirements of the modern city are so great that the burden of taxation will inevitably be heavy. Improvements in the city plan may increase values to such a degree that they would be cheap at almost any price, but if the plan can be so made as to avoid the necessity for destructive changes, both the city at large and the individual property-owner will be the gainers. To defer the correction of mistakes which are quite apparent in well-developed sections of the city, or to put off the adoption of a broader policy in those in process of development, because land is expensive and costly improvements would be destroyed, is not unnatural, even though it be unwise. To fail to take advantage of such object-lessons in parts of the city where there are few, if any, improvements, or where the street plan has not yet been fixed, is the height of folly. Every large city furnishes numerous instances of changes manifestly desirable but deferred until their cost has become prohibitive. To

show the money value of a good plan, not by forcing exaggerated values at some points, but by stimulating a healthy growth, through ease of access to all sections of the city, to schools, libraries, museums, parks, and playgrounds, it is only necessary to examine the successive annual assessment rolls of districts so favored. One specific instance will be given. During the sixteen years following the laying out of Central Park, New York, the average increase in the assessed value of real estate in other parts of the then city of New York was about 100 per cent., while in the three wards adjoining the new park the increase was approximately 800 per cent. Increase of population means almost invariably increase in wealth and taxable values. The most notable increase in urban population during the last quarter of a century has been in Germany. A comparison of the rate of growth of six American and a like number of German cities during the last thirty years will bear out this statement. These cities were selected at random by the author some years ago, simply because they had about the same population in 1880 and because they were believed to be typical. The increase by decades is shown in the following table:

Cities.	Pop. 1880.	Pop. 1890.	Per Cent. Inc. 10 Yrs.	Pop. 1900.	Per Cent. Inc. 20 Yrs.	Pop. 1910.	Per Cent. Inc. 30 Yrs.
Cincinnati . . .	225,139	296,309	16.1	325,902	27.7	364,463	42.8
Breslau	272,900	335,200	22.8	422,728	54.9	510,929	87.0
Buffalo	155,000	255,664	65.0	352,387	127.1	423,715	173.4
Cologne	144,800	281,800	94.6	372,229	157.0	513,491	254.6
New Orleans .	216,000	242,039	12.0	287,104	32.8	339,075	56.9
Dresden	220,800	276,500	25.2	395,394	79.0	546,822	147.1
Louisville	123,758	161,005	31.0	204,731	65.4	223,928	80.9
Hanover	122,800	163,600	33.2	235,666	91.0	302,384	146.2
Providence . . .	104,850	132,099	26.0	175,597	67.5	224,326	113.9
Nuremberg . .	99,519	142,523	43.2	261,022	162.3	332,539	234.1
Rochester	89,366	133,896	49.8	162,608	82.0	218,149	144.1
Chemnitz	85,000	138,955	63.5	206,584	143.0	286,455	237.1

It is generally conceded that the most scientific, painstaking, and far-sighted city planning done in recent years has been in Germany. While it may have been commenced for reasons somewhat sentimental and because of a striving for that beauty which had proved a valuable asset in the Latin countries, it has been continued because it was found to pay, and the German cities are fast becoming the most beautiful,

the most orderly, and the most prosperous in the world. This is not a mere coincidence, but the conclusion is justified that scientific planning will promote, to a greater degree than has heretofore been realized, not only orderly development, but increase in population, wealth, and taxable values, to say nothing of the convenience, health, and comfort of the citizens. Many of the European cities have, on account of their antiquity, one great advantage in working out an admirable plan. A serious impediment to their growth has been the old fortifications within which the ancient cities were confined. It was fortunate for them that before they felt it safe to destroy the old walls and moats they had come to a realization of their value in affording sites for a splendid system of circumferential boulevards and open spaces. Perhaps the most conspicuous instance of this use is furnished by Vienna, whose superb Ring Strassen, occupying the spaces formerly devoted to the inner and outer fortifications, with its effective grouping of public buildings and its system of radial thoroughfares, make it, perhaps, the most beautiful of all cities.

In a brief reference to recent progress in city planning at home and abroad sharp distinction should be drawn between the ambitious and often spectacular plans to create civic centers with striking architectural features, and the less sensational, but often more important, efforts to correct, where possible, the present plan, and to provide for future development a scheme which will permanently fix the arteries of traffic and allow as great a degree of flexibility as possible in the filling in of details. The establishment of a civic center, such as that now in process of execution in Cleveland, but which is confined to a limited area, and the more comprehensive plan under consideration by Chicago, which extends over many blocks surrounding the proposed center, are certainly impressive. The former will, and the latter may, be worth while, whatever may be their cost. Their monumental dignity and beauty appeal strongly to the imagination and pride of the citizen, and the courageous optimism of the cities of the middle West and the Pacific coast may bring about their realization, although it will involve the destruction of costly improvements and the entire rearrangement of the street system in their vicinity. Memphis and Kansas City, which once may have been considered somewhat featureless, not to say commonplace, cities, have been developing park and boulevard systems which have already made them notable, and they are doing it because it has been found to pay. Los Angeles, Portland, and Seattle are working out plans

for their future development along lines which would stagger the more conservative cities of the East. Instances might be multiplied of cities which have awakened to the importance of correcting mistakes before it is too late, and providing for future extensions along more rational lines than those of the original plan, and of the striking increase in population, business, and realty values resulting from this awakening. It would be impossible to do so within the compass of this paper, and the author will confine further comment upon progress in city planning to a brief review of what is doubtless the most conspicuous legislation along these lines which has yet been attempted, namely, the Town Planning Act adopted by the English Parliament in 1909. The material for this review was taken from the act itself, from the various explanatory memoranda issued by the Local Government Board to the local authorities, and to an analysis of the act which appeared in the initial number of the Town Planning Review, published by the University of Liverpool.

The underlying idea of this act, which applies not only to every great city, but to every town in England, Scotland, and Wales, is that every urban district has a powerful effect upon the territory outside of its corporate limits. The city plan is not and cannot be bounded by the red lines indicating the city or town limits. In the last analysis every part of a thickly settled country is either included within the limits of a municipal corporation, or is so powerfully affected by its proximity thereto that the entire territory will inevitably be influenced by the operation of a Town Planning Act as general in its application as that of Great Britain. Heretofore no project materially affecting any city, whether that city be great or small, especially one involving the power compulsorily to acquire land, could be carried out without the express authority of Parliament. Almost the only acts which were quite general in their application were those relating to sanitary housing, such as "The Housing of the Working Class Act" of 1890 and its several amendments. The most liberal enactment, so far as the delegation of powers to local authorities is concerned, was that of 1908 with respect to the corporation of the City of Liverpool.

The General Act of 1909 applies to the whole of England and Wales, and, with slight modifications, to Scotland. Its object, as defined in its opening section, is the "securing proper sanitary conditions, amenity, and convenience in connection with the laying out and use of the land and of any neighboring lands."

Upon the Local Government Board has been conferred authority formerly exercised only by Parliament itself, the latter retaining, however, certain veto powers. The area which may be included in a scheme is any land which is in course of development or which is likely to be used for building or for open spaces, roads, streets, parks, pleasure grounds, or incidental works, and may include land already built upon and even land not likely to be used for building purposes, if it is so situated that it ought to be included in the scheme. The Local Government Board may authorize a local authority to prepare a town-planning scheme if the Board is satisfied that there is a reasonable demand or call for such a plan. A scheme proposed and adopted by any local authority cannot become effective unless it shall first have been approved by the Local Government Board, which may refuse its approval with such modifications and subject to such conditions as it may see fit to impose. Before approval by the Local Government Board notice shall be published by the London or Edinburgh Gazette, as the case may be, and if within twenty-one days of the time of publication no interested person or authority objects to the draft or the order of approval, it shall be laid before both houses of Parliament for not less than thirty days during a session of Parliament, and if, before the expiration of thirty days, either house presents an address to the Crown against the draft or any part thereof, no further proceedings shall be taken, without prejudice, however, to the making of a new draft scheme. A town-planning scheme once adopted may be varied or revoked by the same method of procedure as that followed in its original adoption. The Local Government Board is authorized to prescribe provisions for carrying out the general objects of town-planning schemes, these objects being given in the widest terms in a schedule which is a part of the act, including the laying out and improvement of streets and roads and the closing or diversion of existing highways; the erection of buildings and other structures; the provision of open spaces, both private and public; the preservation of objects of historic interest or natural beauty; sewerage, drainage, and sewage disposal; lighting; water supply; the extinction of private rights-of-way or other easements; the disposal of land acquired by the local authorities; the removal, alteration, or demolition of any work which would obstruct the carrying out of the scheme; the making of agreements by the local authorities with owners and by owners with each other; the right of the local authorities to accept any money or property for the furtherance of the

object of any town-planning scheme, and the regulation of the administration of such money or property; the limitation of time for the operation of the scheme; the coöperation of the local authorities with the owners of land included in the scheme, and the imposition upon land whose value is increased by the operation of a town-planning scheme of the sum to be paid on account of their increase in value.

In addition to these general provisions there may be incorporated in any scheme special provisions defining the area and the responsible authority, and especially dealing with local conditions, and these special provisions may vary or supersede not only the general provisions, but even Acts of Parliament, although when any general act of Parliament is thus contravened, special opportunity is given either house by resolution to reject the scheme before it is finally approved.

A town-planning scheme may originate in any one of three different ways:

1. Land owners may formulate a scheme which the Local Government Board may authorize, or after public inquiry may compel the local authorities to adopt.
2. Any representation may be made to the Local Government Board that a scheme ought to be prepared by a local authority, and the Board may, after public inquiry, order a scheme to be so prepared.
3. A local authority may prepare a scheme, but before any public money is expended, a prima facie case must be made out and the sanction of the Local Government Board obtained.

The responsible authorities are given abundant power to enforce an adopted scheme by removing any building or work executed in contravention of the scheme, and by carrying out, at the expense of the person in default, any work which is so delayed as to prejudice the plan, and the responsible authorities may be compelled by the Local Government Board to exercise these powers.

The expenses incurred by a local authority may fall under three different heads:

1. The cost of preparing and promoting a scheme. The Act contains no provision as to this expense beyond the fact that it will be charged in the general tax of the district.

2. The cost of acquiring land for the purpose of carrying out a scheme. Compulsory powers of purchase may be exercised by order of the Local Government Board without statutory confirmation, unless an impartial public inquiry shows that the land is unsuitable

for the required purpose or cannot be acquired without undue detriment, in which case any order made by the Local Government Board must be confirmed by Parliament. The price to be paid for land compulsorily acquired is to be determined by a single Government Board arbitrator, and no additional allowance will be made by reason of the purchase being compulsory.

3. Compensation may be allowed the land-owners for injury, and this compensation is to be determined by a single Local Government Board arbitrator, but no allowance is to be made for the limitation which an adopted scheme may impose as to the number, height, or character of the buildings which may be erected, nor for any requirement of a scheme which may be in force, nor for anything done after application has been made for the right to prepare a scheme. The principle of betterment is also recognized to the extent of one-half the increase in the value of property by the scheme.

It will be seen that the powers conferred upon the Local Government Board by the Town-Planning Act are extraordinary, and perhaps unprecedented, and it is quite probable that the success or the failure of the act will depend to a large degree upon the manner in which the power is exercised.

The recent interest in questions relating to city planning can be largely credited to architects, landscape engineers, civic organizations, and those who, from motives which may be altruistic or selfish, wish to see their city made more liable and attractive. To these men and bodies must be given much of the credit due for the movements which have resulted in the establishment of dignified civic centers, the effective grouping of public buildings, and in many cases the cutting through of new thoroughfares. In few instances have engineers taken a conspicuous part in the planning or execution of such improvements other than the mere work of physical construction. If the principles enunciated in this paper are accepted as sound, it must be admitted that these spasmodic efforts, admirable as may have been their results in many cases, are not city planning. They are often spectacular, and they attract the admiring attention of the public. Real city planning is more fundamental and will render unnecessary an enormous destruction of property before real constructive work can be begun.

City planning in the sense in which the author has used it is almost wholly constructive. Some demolition of improvements there must be, but it should take place before they have assumed great value,

and before the sections in which they are located have assumed a fixed character. The work will not be done in the limelight, and the men who do it will not receive the credit and the applause which will be the portion of those who might later, at great public inconvenience and expense, correct mistakes which but for their foresight the original planning might have made.

While conferences and exhibitions of city planning are doubtless of great benefit in enabling one to see what is going on in other cities, and in demonstrating the public interest in the subject, their greatest value consists, perhaps, in giving those responsible for the development of a city plan the opportunity of seeing the mistakes which other cities are striving to correct.

The creation of a city plan is no work for an expert temporarily retained for the purpose; it is no work for a commission specially created for the task, and upon which there is an attempt to establish a balance between engineers, architects, civic workers, business men, etc. It is work which must be carried out patiently every day in the year. The services of experts should be secured, and their judgment might properly be controlling in some respects. This is no one-man task, but it is essentially the work of the engineer, or rather of the regular engineering staff of the city. If the engineers are not alive to their opportunity; if they are not ready to profit by the experiences of other cities in all parts of the world; if they undertake the problem as one of more or less precise surveying; if they are content to prepare a plan for undeveloped portions of the city along the conventional lines followed in the older portions, notwithstanding the palpable defects of older plans—then they need not be surprised if the architects and the landscape engineers are subsequently called in to correct their mistakes, or if the idea becomes prevalent that an engineer is qualified only to build a city after it has been planned by some one else.

Reference to what has been done and what is being done in Philadelphia has been purposely deferred until this subdivision of the subject should have been reached, as this city furnishes, perhaps, the best example of the results which may be attained by the patient but systematic study of a city's growth and needs, which its regular engineering staff should be in position to give. Philadelphia inherited from its founder a rectangular plan of the most conventional type. Its early expansion was doubtless along the prolongation of the lines laid down in that original plan. The great value of diag-

onal streets appears to have been recognized, however, and these were not only provided to establish direct connections with the highways outside the city limits, but they were extended toward the center, missing connections were supplied here and there until, before the public appears to have been aware of the fact, certainly before the professional city planner descended upon the city, the engineers of Philadelphia had not only gone a long way toward correcting the inherent defects of the original plan, but had provided a comprehensive and admirable scheme for future development. It is probable that much study and great expenditures will still be required to perfect this system in the older parts of the city, but there is much satisfaction to be derived from the knowledge that the mistakes of the past are not being repeated in the newer portions of the city, as is so generally the case throughout this country. Notwithstanding these facts we do not read or hear much of Philadelphia in city-planning literature and discussions, even though in this city has been held the greatest city-planning exhibition ever given in this country. This confirms the statement, already made, that the most valuable work of this kind, the work that involves a minimum of expense in destruction of improvements to attain the desired results, will attract little public attention or appreciation. The engineer who designs and builds a structure that is well adapted to its purpose and will last for generations will receive little recognition, but if such a structure fails, or if its capacity proves inadequate to increased demands, he who designs one more imposing and flamboyant to take its place will be acclaimed a genius.

The author has no desire to detract from the credit which has been given to men like Carrére, Burnham, Brunner, Olmsted, Nolen, and a number of others, for the admirable work done or proposed by them to redeem some of our cities from the commonplace. Their plans are, many of them, inspiring—some of them extravagant beyond hope of realization. Their genius can and should be availed of in the constructive work of making our cities beautiful, but the destructive features of their plans could be largely avoided if the engineers generally, as they appear to have done in Philadelphia, would bestow more careful study upon their task of preparing the original plan.

The general principles which should govern the creation of a city plan may be summed up under three headings:

Provision for future growth.

Reasonable regard for the interest of the property owner and the tax-payer, as well as the public.

Economy, or an attempt to secure what is needed at a minimum of expense.

In making provision for future growth, some imagination is required. There appears to be a belief, more or less general, that imagination is something that the engineer should studiously avoid, but failure to exercise it is probably responsible for many of the defects in original city plans made by engineers. By imagination the author does not mean a capacity to dream and to produce results which he may think artistic, but the ability to estimate the future by the past, to grasp the probable, and even possible, growth and development of the city in population and commerce, to anticipate the various needs of a great number of people, to repress, to a certain degree, his own preconceived notions of the precise lines along which a plan should be evolved, and to take counsel with others and not to limit such counsel to men of his own profession. No human being can foresee the precise lines along which a city will grow. Electric traction, the automobile, and the telephone have made it possible to extend the radius of action of the average citizen to a degree which would scarcely have been credited a generation ago. The quiet suburb of the last decade has already become an important business center of the city of today. While no one can anticipate such changes, it is a mistake to assume that the character of any particular district is permanently fixed. The problem is to devise a plan so flexible that, with a minimum of expense for rearrangement, it can adapt itself to changed and changing conditions. This is what is meant by the exercise of imagination tempered by common sense.

Regard for the interests of the property-owner as well as the public implies a capacity to reach a desired result along the lines of least resistance, and to discuss frankly and freely with the owners of property the rational and most economical development for each section, insisting, however, upon the superiority of the public to the private interest. While directness and continuity are essential in main traffic thoroughfares, it must be remembered that by far the largest mileage of city streets are not traffic thoroughfares, but will be devoted to dwellings, and that their function is to provide light, air, and access, with facilities for reaching as readily as possible the main traffic thoroughfares upon which will be located the shops and places of amusements, and which will be the route to be followed in reaching more distant places of recreation, such as the public parks. To plan a series of residential streets with the same directness and continuity

which should be given the traffic streets is not only unnecessary, but the result is unpleasantly monotonous and uninteresting, with no compensating advantage. There is no reason why individual preference and ideas should not be exercised by the private developer, provided that his development does not interfere with the main arteries of traffic, and provided, also, that it is not inconsistent with good sanitary conditions. Some of the plans evolved for private development may cause a distinct shock to the engineer. This will do him no harm; in fact, he needs it occasionally for his own good.

Many developments made by individuals or corporations before the completion of the plan for the district in which they are located could be incorporated in the final plan, provided there were a disposition on the part of the developers to confer and coöperate with the city authorities before making their improvements. Inasmuch as property sold as city plots depends for its value upon a street system which will afford access, it would not appear unreasonable to prohibit by statute the sale or offering for sale of lots in unmapped sections, unless the proposed plan of streets should first have been submitted to the municipal authorities for their examination, approval, or correction in order that the proposed streets might be made to conform with the general plan of main highways proposed for the part of the city in which the property is located. A reasonable time—say six months—should be allowed for the acceptance, amendment, or rejection of the plan submitted, and if the opportunity to do so were not availed of within that time, the owner might be absolved from any obligation to further delay the improvement and sale of his property. Such a requirement would not appear to be an unreasonable restriction upon the right of the owner to use his property to the best advantage, but would be a recognition of the right of the city to control in some degree the street plan upon which that property depends for its value, while the assurance to purchasers that the street plan is definitely fixed and that the homes they build will not be destroyed by a rearrangement of the plan would add materially to the value of the property. It is quite probable that reputable real-estate developers would not oppose legislation of this character. Philadelphia does not appear to suffer from this practice as much as do other American cities, first, for the reason that its city plan seems to have been developed well in advance of improvements, and, secondly, because the erection of buildings within the lines of streets which have been laid down by competent authority is forbidden except at the risk of the

builder, who can recover no damages for the destruction of buildings so erected. It is said that this statute, although specifically referring to streets, has been construed as applying to parks also, so that Philadelphia appears to have the power to preëmpt land which may be needed for street or park purposes, and prevent the erection thereon of buildings for the express purpose of securing an extravagant award. Such a power may be abused by the city as well as by an individual, but it may be assumed that the retention of such power by the city is good evidence that it has been used wisely and fairly. The disposition in other States and in other city charters appears to have unduly emphasized the rights of the individual as against the rights of the community. This may be a heritage of our English common law, for it has been said that in England the law is disposed to treat the State as an instrument of the citizen, while in Continental Europe the interests of the State are paramount, and those of the individual are incidental and entirely subordinate to the greater interest.

Time will not permit a discussion of the important principle of excess condemnation and the enormous value which this right would confer upon the city in developing, and especially in correcting, its plan. The beneficial working of excess condemnation in Europe is well known. In this country State legislatures have been loath to grant such a power to any municipality, for the probable reason that it is believed that it would be used either recklessly or corruptly, or that it would encourage speculation in real estate by the city. While these are the reasons usually given for opposing the right of excess condemnation, many of those who have objected to it have undoubtedly been prompted by a desire to have perpetuated a system which those who are shrewd enough to acquire property on the line of some great improvement have found so enormously profitable to themselves. This is particularly noticeable in cases where it is necessary to extend or widen existing streets through the built-up sections of the city, but it would be particularly advantageous in securing a system of small or neighborhood parks in the undeveloped sections of the city.

If acreage property could be secured even before the development of the street system, and of sufficiently large area to permit the laying out of a symmetric park when the street system is finally determined, leaving the surplusage for sale, the financing of a system of neighborhood parks in the undeveloped sections of the city would be a very simple matter. In disposing of the surplus property, sites for schools

and other public buildings, commonly bought at enormous expense, could properly be reserved for future use, and it is not unlikely that both park and building sites could thus be made to pay for themselves. In the cutting through of new or the widening of existing streets in built-up sections of the city the simple right to acquire entire parcels, portions of which are needed for the new or widened street, and the sale of the surplusage after the street shall have been constructed along the new lines, would, on account of the enhanced value, enable the city to recoup a large portion of the expense, instead of adding the entire cost to the permanent debt of the city, and at the same time enriching abutting owners, first, through awards made for damage imposed, and then for the enormously increased value of the property which is left.

As already stated, there is no reason why subordinate residential streets should follow long, straight lines. This is in a measure true of main traffic thoroughfares, but in them the changes in direction should not be permitted materially to increase distance or impair directness. Topography and existing improvements may be such that expense may be saved by easy changes in direction, while at the same time the street will gain in interest and admirable sites will be afforded for important buildings, the lack of which sites is so painfully evident in a rectangular street plan.

It may be thought that the title of this paper has been forgotten, and that it has been devoted to a discussion of what the city plan is, and the effect of an intelligent plan upon the growth of the city, rather than to an attempt to point out the relation which the municipal engineer should bear to city planning. The writer has endeavored to draw a specification, crude and incomplete though it may be, of the materials to be used and the work to be done in the preparation and development of a rational city plan. Who will best measure up to the specification—the architect, the landscape architect, the civic worker, the lawyer, the business man, the real-estate developer, or the municipal engineeer? As already stated, it is no one-man job. The advice of every one of the above would be valuable and should be sought. The engineer will naturally be the first man on the ground. If he is a broad man,—a man of imagination, of human sympathy, of business ability, with a proper sense of proportion,—he will so lay the foundation of the city plan that an orderly development will follow, and a large part of the vast sums required to reconstruct the plan and make it fit changing conditions or adapt

it to rapid growth will be saved. Some changes will inevitably be required as the city grows, but the necessity for them should be discovered by the engineer, who should not be content to let things drift until conditions become intolerable, and the task of doing that which is obviously necessary is intrusted to some one else, who in connection therewith will be tempted to create at great and perhaps needless expense a monument to himself which will be founded, alas! on the incapacity, the indifference, or the lack of vision of the municipal engineer.

DISCUSSION OF MR. NELSON P. LEWIS'S PAPER.

Mr. J. C. Trautwine, Jr.—Mr. Lewis's paper might appropriately have been entitled "The Inevitability and the Profitableness of Municipal Socialism."

By providing and improving streets, parks, etc., cities give back to the individual not only infinitely more than he has paid in taxes, but infinitely more than he could obtain by any individual effort or expenditure.

In return for a relatively insignificant sum, taken from him in the shape of taxes, the individual is made the virtual owner of all the street and park systems of the civilized world, to say nothing of water supply, sewerage, etc.

So enormous is the economy of public (as compared with private) expenditure, that even apparently unwise and extravagant municipal expenditure is pretty sure to be highly profitable, This is why our graft-ridden cities can borrow money at lower rates than can our perhaps more honestly managed private corporations.

This being the case, municipal activity would develop far more rapidly than it does, were it not that its benefits (like the air we breathe) are so all-pervading that, for the most part, we take them for granted and practically ignore them.

Partly on this account, and partly because of antecedent centuries of individualistic practice, our eyes are holden, and we fail to see that the public wealth of our poorest citizen is infinitely greater and more important than the private wealth of the millionaire. Our appreciation of these benefits thus lags ever far behind the benefits themselves.

This blindness leads us to protest against increase of taxation; and yet the meanest of us would refuse to have all or any portion of his taxes refunded to him, if this involved a proportionate refund to all other taxpayers, with corresponding damage to the existing condition of his city.

For the first time within a generation Philadelphia is now blessed with an upright administration; and it is of the utmost importance to all of us that this administration be encouraged to spend the people's money freely, seeing that it will surely come back to them a hundredfold.

George S. Webster.—Mr. Lewis' admirable paper is a very valuable addition to our literature on city planning. It indicates that he has had a long and extended experience in work of this character, and the principles which he has laid down are those which are recognized as essentials by men actively engaged in city planning.

The rapid growth of our American municipalities is such that we cannot hope to continue to carry on the increasing volume of business at one central location.

Although there will be one center of greater importance than the others, the people should be encouraged to establish other centers for the transaction of business.

In many of our cities, particularly in Philadelphia, the street system is now so congested that there is not sufficient space, either on the surface or under ground, to care for those necessities which are so important for the comfort, convenience, and health of the people.

I agree with Mr. Lewis that it is the duty of the engineer to place upon the plan and to provide for those main avenues of transportation which are so essential for the development of every city and its adjacent suburbs, and in planning or replanning avenues of communication provision should be made and direct routes of travel laid out leading to the various centers of trade, and also to the towns in the vicinity. By planning these great avenues of communication their harmonious development will result.

The cities of Germany appear to be growing more rapidly than those in our country, yet many American towns are developing with remarkable rapidity, and unless we anticipate the needs of the future by intelligently planning for this great growth, there will be much tearing down of buildings and reconstruction of streets to furnish the necessary facilities for the carrying on of trade and the transaction of business.

It is gratifying that so many cities, both in this country and abroad, are preparing comprehensively for the future, not only in providing sufficient highways, but also open places for parks, playgrounds, and for the purpose of erecting public and semipublic buildings.

These matters must necessarily receive greater attention in the future as the people at large are realizing the necessity of providing healthy environments for the proper development and growth of cities.

B. A. Haldeman.—I feel that I can join with Mr. Trautwine in saying that practically every sentence of Mr. Lewis's paper provides a text for a sermon—there are so many things in it that all of us who are interested in town planning and in the proper development of a city can take home and study.

One very interesting part of it is that in regard to the comparative growth of American and German cities. It is somewhat surprising to learn that German cities have grown so much more rapidly than American cities, for the idea is prevalent that the opposite has been the case. I think a reason for this is that the methods of planning and taking care of the population of the German cities have developed them more completely. The German cities are now planning much better than formerly, and are taking advantage of their opportunities in the best possible manner. Although the growth of our American cities has been very rapid, it is probable that unless in our town planning we are able to devise ways and means for getting our people more out into the country, congestion is likely to increase more rapidly in the future than it has done in the past. Big cities, such as Boston, New York, and Philadelphia, must provide better measures for taking care of the growing population and providing the things that that population is going to need in the conduct of its daily life and business; unless they do this, they will not be doing their duty by their people.

Mr. Lewis has paid the Philadelphia engineers a very great compliment in his paper, which I trust those who have been actively engaged in the planning of Philadelphia deserve. I regret that more of the engineers engaged in that planning are not here tonight.

Philadelphia occupies the position, possibly, of having the best laws in the United States on town planning. We have laws which other cities are striving to obtain. The growth of interest in city planning in the United States in recent years has been remarkable. There has been a sort of competition among many of the cities in preparing their plans. I think those who have kept in touch with these plans recognize that many of them have been overworked and show projects which no one can hope to carry out; but they have served to advertise the cities, and they have served to bring the attention of the people to better things and to show the necessity for planning for them. There is no reason why American cities should not develop as beautifully as those of Europe; there is no question but that the cities of Europe, and especially those of Germany, are the most beautiful cities of today. Paris has many splendid avenues, but you do not have to go far off them to find streets that are anything but beautiful or creditable to the city.

It has always seemed strange to me that the examples we have had before us for years have not taught us to plan our cities more intelligently. For instance, we have had before us Wren's Plan for London, suggested in 1666; we fully appreciate what the advantages of that plan would be today, yet we are permitting the conditions that have grown up in London to grow up in this city at a time when we could prevent or improve many of them.

Chairman: I think Mr. Lewis has called attention to a feature that is as important as any that has been brought out in previous discussions of this work, and that is any work of this character should be done by people who make a profession of just such work. I will cite a case in point that attracted my attention recently. It relates to Germany. I ran across an advertisement in an engineering paper in which the authorities of a southern German city were advertising for a mayor for their city, and they wanted an executive officer whose business it was to be mayor.

Robert Schmitz.—The paper just read is an admirable one and shows much study. It was especially interesting to me in its comparison of the American with the German cities and the increase in the German cities. While I believe this is due to some extent to the city planning which has been going on there, as outlined by Mr. Lewis, it is due also to a number of other causes; that is, the increase in the German population above and beyond what the increase in population was in the American cities is due also to other causes. One of these causes is perhaps to be found in the method of government in Germany. The German cities use a plan for keeping their people at home, and they avoid the necessity of their people going to the United States, as is the case with the people of most other countries of Europe. The German families, as a rule, are large; that will, of course, add considerably to the population, especially if they stay at home. Then the government wisely provides an old-age pension fund for working-people. It is the working-people who come to this country from other parts of the world, as a rule, and not the people who are situated in better circumstances; and it is to keep the working-people at home that the German government has striven to develop a plan which will be as nearly perfect as could be devised. The old-age pension system in Germany no doubt plays a very important part in the rapid increase, not alone in the population of the German cities with which Mr. Lewis has compared the American cities, but also in other parts of Germany—in the

suburban towns and the country districts. If, in addition to the table which Mr. Lewis showed to us, we had another table comparing as nearly as may be the American cities with French cities, for instance, or Italian cities or Russian cities of the same or nearly the same population, we might perhaps reach a more definite conclusion as to the precise effect which the city planning would have on the population, because such a comparison would, to some extent, eliminate all other factors to which I have referred.

Philadelphia, with its rectangular streets and quite a number of diagonal streets, is no doubt as well situated or in as good a position for the adaptation of a comprehensive plan, such as has been spoken of by Mr. Lewis tonight, as any other city of the United States. Still the apparent introduction in some of the European plans of crooked streets in place of straight ones is not always, to my mind, the wisest plan, and I hardly believe that the introduction of crooked streets in place of straight ones would be considered the best policy in our plan, because traffic will naturally seek a straight course to reach its destination in the shortest time. Yet we all know that crooked streets sometimes cannot be avoided, as, for instance, when the grades are such as to make it advisable to deviate from the plan to avoid steep hills.

Mr. Lewis.—I would like to add a word in connection with what the last speaker has said. In considering the figures showing the increase in population of certain German cities over certain American cities, it would be well to bear in mind the fact that, during the last decade, or from 1900 to 1910, the increase in population of Germany was 16 per cent., while the increase in that of the United States was 21 per cent. There must have been, therefore, a very great drift of rural population toward the cities in Germany—a much more notable drift than was the case in this country during the last decade. A great number of the immigrants to the United States go to the cities. In New York the foreign-born population is increasing at an enormous rate. Yet, notwithstanding the movement of our own people from the country to our cities, and notwithstanding the fact that the rate of increase in the population of our entire country has been about 25 per cent. greater than the rate of increase in Germany, the German cities have still grown faster than ours.

I think it is only fair to say that in some German cities, with wide and beautiful streets lined with imposing buildings, the conditions of housing are said to be worse than those which prevail in London or in the smaller manufacturing towns of England, where the single-family house is the rule rather than the exception. The higher land values in German cities resulting from the greater cost of the improvements appears to compel a more intensive use of the residential area in order to secure a fair return on the investment.

One gentleman has confessed to a horror of increased taxation. That is inborn; we naturally dread it, and nobody likes it; but, in my opinion, we in this country do not know what taxation is in comparison with that in Europe.

Mr. Haldeman.—Although the streets and buildings of German cities are beautiful, many of the fine façades conceal conditions which are worse even than those in London. This is so true that there is probably no place in the world where such strenuous attempts have been made to improve the conditions of the people, and these attempts have produced what is called the "Zone System," under which municipal councils control the use and occupancy of land. For-

merly, people who were drawn to the towns were forced to take the best accommodation they could get, and for years they lived in any kind of a place that would cover their heads. Naturally, that reduced the efficiency of the working-man, and the German authorities found it necessary to do something radical to ameliorate the housing conditions. At first they established the practice of building large tenements which housed hundreds of people, but that failed to solve the difficulty to the extent which the authorities desired, and they finally succeeded in establishing laws limiting the number of houses per acre, the height of buildings, and regulating the entire building up of the cities; under these laws the municipal councils mark out the areas of the cities which are to be devoted to the various kinds of residences—two-story, three-story, four-story, and so on; in some sections the houses are permitted to be built in rows; in some only twin houses are permitted, and in others only single houses. In Austria enterprises are also limited to certain sections.

In addition to the regulation of housing conditions industrial colonies have been formed; they are laid out in an attractive manner, and the houses are built with due attention to neatness and comfort, and with yards and gardens around them. Sometimes there are four dwellings in a group and sometimes twin houses; the accommodations in these are as good as the one-family house that we have here in America, and in some respects they are better. In some cases, under the law in Germany, a house cannot be built in such a way that the sunshine cannot enter each window of a living-room during some part of the day. That may seem like a difficult task, but the German architect and town-planner performs it just the same.

So far as other German buildings are concerned, I was inside some large office buildings where it was not necessary to use artificial lighting in the day-time—and that is true of only very few office buildings in this country. It is somewhat curious, when we come to study any of these problems of vital interest, to find that we must turn to Germany for the best and most progressive examples of things that are actually being done, and being done well, and that are being done in the interests of the people and not in the interest of the men who own the land or build the houses.

Edward Hutchinson.—Instead of lamenting that our cities are not growing as rapidly as those in Germany, I think we should congratulate ourselves. Consider the area and population of this country as compared with the area and population of Germany: here we have thousands upon thousands of acres for our population to distribute in, whereas in Germany it is all condensed. While our growth in the last decade has been 21 per cent., in Germany their whole growth has been only 16 per cent., which I think is sufficient cause for congratulation on our part.

Chairman.—I would like to contribute a little something to this discussion from my own personal knowledge of Germany. Of course, we are not talking so much of the smaller towns as of the larger cities, where the conditions cannot be helped. The city engineer must provide for conditions that are likely to get worse rather than better. Take a large city like Berlin, which can be well compared with our larger cities. The German authorities make it a law that no more than a certain percentage of the area of any plot of ground may be built upon. I do not know what the percentage is—it varies with the towns; I think it is about

60 per cent. That law makes it impossible to put up a single tenement house, but compels the taking of a large area and the building on that large area of a suitable dwelling. The next requirement of the law is that every room in that house, every space that is not absolutely a clothes-press or similar compartment, must have a full-sized window opening to the air. That does not mean a shaft which makes an excellent draft, but it means an air-space which is, if my memory serves me correctly, 60 per cent. of the height of the highest adjoining wall. These buildings are generally put up in the form of an inclosure around a large open central space.

The next requirement is that the building must be fireproof: the doorway to the court must be constructed and located in such a way that the fire-engines can drive through—something like the entrances to our City Hall.

Mention was made of the fact that very imposing exteriors oftentimes cover wretched interiors. That is no longer true of the German cities in those portions that are growing. They do not pull down and build immediately any more than we do, but they do not allow their slums to grow. There are occasionally to be seen modern frontages, and behind them a huddle from an older period, but that is only a disappearing remnant.

Municipal work is better done in Germany than in any other country in the world; not because they are more competent than anywhere else, but over there people go into the governmental service as an absolute career. Here a boy makes up his mind what he is going to be,—a doctor or a lawyer, or what not,—while over there a boy decides for some line of public work: his whole career is shaped to that from the beginning, and in the spirit that his chosen career is his life's work. When he gets his appointment, he knows that he will go along the whole line of promotion from position to position. There is not very much pay, but he knows that if anything happens to him he will be taken care of, as will also his wife and his children, if he has any. Therefore these people do not need to get very high pay. They have no heavy expenses, and they live up to the handle of their incomes. I believe that absolute certainty of office and the fact that they follow a chosen career from the beginning make for efficiency more than any other one feature. Over there citizenship in a town has nothing to do with office holding—municipal office is not a plum awarded by a successful ward boss.

HENRY WILSON SPANGLER.

1858—1912.

(By courtesy of the Engineering News.)*

Professor H. W. Spangler, Whitney Professor of Dynamical Engineering at the University of Pennsylvania, died at his home in Philadelphia on March 17, 1912, of heart disease, after a serious illness of several months. The first attack of this ailment befell him in the late summer of 1909, while in the wilds of Maine, his sole companion being a guide. Upon partial recovery he resumed his duties at the University, with characteristic determination, and against the protests of his friends, until the progress of his disease compelled him, three or four months ago, to relinquish all active duties.

Henry Wilson Spangler, son of John Kerr and Margaret Ann (Wilson) Spangler, was born at Carlisle, Pa., on January 18, 1858. He was graduated with high rank at the United States Naval Academy, as Cadet Engineer, with the class of 1878. Two other members of that class have attained to prominent positions in the field of engineering education, namely, Professor Ira N. Hollis, head of the Engineering Department at Harvard University, and Professor M. E. Cooley, Dean of the Department of Engineering at the University of Michigan.

Professor Spangler was assistant engineer in the United States navy from 1878 to 1889, although for about half that period he was connected, on detached service, with the Faculty of the University of Pennsylvania, first as Assistant Professor of Mechanical Engineering from 1881 to 1884 and from 1887 to 1889, and then as full professor, holding the Whitney Professorship of Dynamical Engineering. During the Spanish-American War in 1898 he served for a brief period as chief engineer in the United States navy. With the exception of that short interval, he was in the service of the University as the head of the Mechanical and Electrical Engineering Department continuously from 1887 until his death. The high standard of excellence to

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*This memoir was prepared by Prof. Edgar Marburg, at the request of the Engineering News.

which this department has attained is due largely to his remarkable talents as a teacher and his pronounced ability as an executive officer.

When he assumed his duties at the University the Department of Mechanical Engineering was housed in a single room on the third floor of College Hall, its equipment consisting only of a wooden model of a locomotive valve gear and a Crosby indicator. A small laboratory, in which the principal features were a 5 H.P. vertical boiler and a 4 by 4 inch vertical engine, connected by belt to two dynamos, was afterward installed in the basement. The establishment of a central lighting and heating plant by the University in 1891 afforded the desired opportunity of erecting, in connection therewith, a building devoted to instruction in mechanical and electrical engineering. Within two years after its construction the number of students had increased to such an extent that the capacity of this modest building became overtaxed. That condition continued until the completion, in 1906, of the present Engineering Building, affording accommodations to all the engineering departments of the University, in which the aggregate registration this year is 733.

For many years Professor Spangler also rendered highly efficient services to the University as Director of the Light, Heat, and Power Station, and was intrusted with the design of the heating, lighting, and ventilating installations for the many important buildings erected by the University.

Professor Spangler was the author of a number of standard text-books and numerous technical papers and professional reports. The text-books from his pen embrace "Valve Gears" (1890); "Notes on Thermodynamics" (1901); "Elements of Steam Engineering," in collaboration with A. M. Greene, Jr., and S. M. Marshall (1903); "Graphics" (1908); and "Applied Thermodynamics" (1910). Of these books, "Valve Gears" has passed through two editions, "Notes on Thermodynamics" through five editions, and "Elements of Steam Engineering" is in its third edition. As a writer, his chief characteristics were his painstaking efforts to present the subject in the simplest and clearest manner consistent with the intended scope of treatment, and to keep in view the practical requirements of prospective engineers, rather than theorists. As a teacher, he was lucid, stimulating, progressive, and always intensely practical. His first concern was to help the students to gain a firm grasp of the underlying principles of the subject, and then to encourage them to rely on their own resources in the application of these principles. On no

point, perhaps, was he more insistent than that of individual responsibility, which his students were required to assume in every branch of their work.

In 1896 the University conferred upon him the honorary degree of Master of Science, and ten years later the degree of Doctor of Science.

Professor Spangler was a member of the American Society of Mechanical Engineers, the American Society of Naval Architects and Marine Engineers, the American Society for Testing Materials, the Society for the Promotion of Engineering Education (charter member, 1893; member of council, 1893–4; vice-president, 1898–99), the Franklin Institute, and the Engineers' Club of Philadelphia (director, 1891–3; president, 1890 and 1908). He was a member of the Advisory Council of the Engineering Congress at the World's Columbian Exposition in 1893, and of the Jury of Awards at the Buffalo Exposition in 1901. In 1908 he declined an invitation to accept the Directorship of Public Works of the city of Philadelphia.

The Engineers' Club of Philadelphia did him the signal honor of electing him to the presidency for the second time in 1908, which was the first occurrence of this kind in the long history of that organization. The Club had just entered upon a somewhat ambitious plan of expansion, including the acquisition of a modern club-house, at a heavy expense in proportion to its normal resources. In its quest for a man of the right qualities of leadership—at once sound and progressive—during this critical period, the choice fell naturally upon Professor Spangler, whose acceptance of the office meant inevitably its administration with the same self-sacrificing fidelity with which he met every responsibility that fell to his lot.

Endowed with quick initiative, resourcefulness, courage, and self-reliance, his qualities of leadership stood out at their best at times of emergencies; such as the destruction by fire of the old Mechanical Engineering Building, and the almost immediate and orderly resumption of activities in an incomplete, new building, with such facilities as could be quickly improvised. A strict and almost military disciplinarian, he was no less rigid in the standards which he applied to himself. The respect and admiration in which he was held by his students ripened into affection as they came to see him at closer range. There were few graduates who failed to turn to him at some time for helpful counsel in the perplexities of later years, or who failed to accept it, even though it ran counter to their own promptings.

He possessed to a remarkable degree the faculty of perceiving

clearly, and almost intuitively, the essential elements of a seemingly difficult problem or complex situation, and he was as quick in action as in perception. Few excelled him in the clear discernment of the fallacies of an argument or in the directness of the challenge of such fallacies. Of a thoroughly progressive bent, he did not allow himself to be beguiled into strange paths by the educational fads and follies of the hour. The business of education was, to him, a serious business, with which liberties were not to be taken lightly.

Professor Spangler was married to Nannie Jane Foreman, of Carlisle, Pa., on December 1, 1881. Their union was blessed with three children, of whom one son, Henry Wilson Spangler, Jr., survives. Professor Spangler's remains are interred in Carlisle, Pa.

GEORGE WALLACE MELVILLE.

JOHN C. TRAUTWINE, JR.

Presented April 6, 1912.

George Wallace Melville was born in New York city January 10, 1841, of Scottish ancestors, whose records abound in evidence of that uncompromising decision of character which so strongly marked him.

After early education in the public schools of Brooklyn and a scientific course in the Brooklyn Polytechnic Institute, he was apprenticed to the proprietor of a machine-shop in East Brooklyn.

Upon the outbreak of the civil war, in 1861, he entered the United States navy as third assistant engineer of a steam frigate, and he remained in the service of the Navy Department until his retirement in 1903, and in intimate relations with it up to the time of his death, on March 17, 1912.

During the civil war he was active in many important engagements, notably in the ramming of the Confederate cruiser "Florida" by the "Wachusett," in Bahia harbor, Brazil, in October, 1864. Melville urged ramming, but the officers of the "Wachusett" hesitated, fearing rupture of her boilers; whereupon Melville, with one fireman, who refused to leave him, operated the boilers and engine of the "Wachusett," and the "Florida" was successfully rammed.

About 1865 Melville took part in surveys on the American Isthmus, looking to the determination of the feasibility of an interoceanic ship-canal.

He was several times stationed at the Philadelphia Navy Yard as assistant to the Chief Engineer.

In 1887, while acting as inspector at Cramps' ship-yard in Philadelphia, Melville was appointed, by President Cleveland, Chief of the Bureau of Steam Engineering, and ex officio Engineer in Chief of the United States navy, and he served in this capacity four terms of four years each, until his retirement, in 1903, serving under the administrations of Presidents Cleveland, Harrison, McKinley, and Roosevelt. Under the Personnel Law of March 4, 1899, he became Rear-Admiral.

To the general public Melville is perhaps best known by his three arctic expeditions: First, in 1873, as engineer officer of the "Tigress," which rescued Captain Hall's "Polaris" party off the coast of Labrador; second, and most notably, in 1879–82, as engineer officer of the "Jeannette," under command of the ill-fated George W. De Long, whose remains were afterward found by Melville, after long search attended by incredible hardships; and third, in 1883, as Chief Engineer of the flagship "Thetis," of the squadron under Admiral (then Captain) Winfield S. Schley, which found and rescued Greely and the survivors of his party at Cape Sabine, North Greenland. For his participation in this exploit Melville received, from Congress, a gold medal and an advance of fifteen numbers in rank. The two expeditions last named are described in his book entitled "In the Lena Delta," Boston, 1885.

Among Melville's numerous inventions was a hinged periscope for submarines, enabling them to operate in shallower waters than were practicable with the fixed type. In coöperation with Mr. Henry G. Bryant, recently President of the Geographical Society of Philadelphia, he devised a sealed cask, to be used by navigators in arctic seas, for the purpose of showing, by their drift, the directions and velocities of ocean currents.

His best-known invention, however, is the speed-reduction gear for turbine steamers, recently elaborated in conjunction with his late partner, Mr. John H. Macalpine, and constructed and successfully tested by Mr. George Westinghouse, at the works of the Westinghouse Machine Company, East Pittsburgh. At a meeting of this Club, held January 6th of the current year, Rear-Admiral John R. Edwards read, for Admiral Melville, who was present, a paper explaining the design, construction, and application of this speed-reducer.

One of Melville's most noteworthy contributions to the literature of applied science is recorded in the "Report of the U. S. Naval 'Liquid Fuel' Board," showing the relative efficiencies of coal and of liquid fuel, as determined by a series of tests made under his direction and prosecuted uninterruptedly for twenty-eight months. The report was published at the Government Printing Office, Washington, in 1904.

In a paper printed in the Annals of the American Academy of Political and Social Science, July, 1905, Admiral Melville expressed the view that "our voluntary assumption of responsibilities beyond our natural boundaries is, from a naval viewpoint, a serious weakness," and that the building of the Isthmian Canal, "while in a purely naval

sense of the highest value to the United States, also imposes a heavy burden in its maintenance and defense."

In The North American Review for June, 1911, he expressed the belief that the loss of the battleship "Maine" in Havana harbor was due to the explosion of her own magazines.

Melville was an Honorary Member and Past President of the American Society of Mechanical Engineers, Honorary Member of the Engineers' Club of Philadelphia (elected May 4, 1901), and a member of the American Society of Civil Engineers, of the American Society of Naval Engineers, of the Franklin Institute, of the National and Philadelphia Geographical Societies, of the National Academy of Sciences, of the Philadelphia Academy of Natural Sciences, and of many other organizations, technical, scientific, patriotic, and social.

As President of the Friendly Sons of St. Patrick he was to have delivered his valedictory address at the annual banquet on Monday, March 18th; but he died on St. Patrick's day, the 17th.

He received degrees from the Stevens Institute of Technology, from the University of Pennsylvania, from Harvard, Columbia, and Georgetown Universities, and from the Czar of Russia.

He was active in securing the erection of the Barry monument in Independence Square, Philadelphia, and took part in the ceremonies of its unveiling.

Notwithstanding several attacks of heart failure during the last two months, Admiral Melville visited Washington during last month, in connection with the use of the Melville-Macalpine speed-reduction gear upon Government vessels.

His death, by paralysis, occurred at his home, 620 North Eighteenth Street, Philadelphia. He was twice married—the second time, in October, 1907, to Miss Estella Polis, of Philadelphia, who died in 1909. He is survived by two married daughters.

His personal appearance was strikingly in keeping with his rugged, forceful character. His erect, well-knit, robust frame was surmounted by a large, leonine head, crowned with long white hair. It is said that an artist, commissioned by the German Emperor to paint a typical American head, wandered about in this country for some time in despair of finding such a head, until, seated opposite Admiral Melville at a banquet, he at once saw that he had found the object of his search. The resulting portrait is said to hang in the Emperor's gallery with the simple title, "Amerika."

Melville was a man among men, rejoicing in their comradeship

and in the warm regard in which they held him. Although his life was devoted to the service of his country, he took no interest in that scramble for place and power which we miscall "politics," and it was his boast that he had never cast a vote.

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, March 16, 1912.—The meeting was called to order by Vice-president Hewitt at 8.20 p. m., with 99 members and visitors in attendance. The minutes of the Business Meeting of March 2d were approved as printed in abstract. Mr. H. H. Quimby, Chairman of the Committee on Public Relations, presented the following resolution, which was unanimously adopted:

"*Resolved,* That it is the sense of this Club that the patent laws of the United States are in need of revision, in order to safeguard more completely and equitably the interests of both inventors and the public, and that to this end the President of the United States should be authorized by Congress to appoint a commission of competent persons to make a study of the subject, and suggest such legislation as may appear to be wise and efficacious."

It was further moved and carried that the Secretary be instructed to transmit a copy of this resolution to Congress.

Mr. B. A. Haldeman, chairman of a special committee appointed to represent the Club at a conference in the Mayor's office on "The Promotion of the Systematic Planting and Care of Shade Trees in the City," moved the adoption of the following resolution, which also was carried:

"*Resolved,* That the Engineers' Club of Philadelphia recommend that the sum of $50,000 be appropriated by Councils to the Commissioners of Fairmount Park, acting as the Shade Tree Commission of this city, to be used in encouraging and assisting the planting of shade trees in the streets of the city, and in maintaining such trees as now exist or may hereafter be planted."

Dr. John A. Brashear, of Pittsburgh, Pa., presented the paper of the evening, entitled "Stellar Evolution," which was followed by short addresses by Professor Charles L. Doolittle and Professor M. B. Snyder. On motion of Mr. John C. Trautwine, Jr., the thanks of the Club were extended to Dr. Brashear for his extremely interesting and instructive paper.

Business Meeting, April 6, 1912.—The meeting was called to order by Vice-president Plack at 8.30 p. m., with 82 members and visitors in attendance. The minutes of the Business Meeting of March 16th were approved as printed in abstract.

Dr. Marburg presented a memorial of Henry Wilson Spangler, past President of the Club, prepared by Dr. Marburg and Professor Easby. Mr. S. M. Swaab presented a memorial of George W. Melville, prepared by Mr. John C. Trautwine, Jr.

Following a report of the Tellers, the following were declared elected to mem-

bership: Active, Morris L. Cooke, William H. Hultgren and Alexander T. Lewis; Junior, Carl D. Buchholz and Frederick W. Reuter.

Mr. George W. Tillson presented the paper of the evening, entitled, "Recent Improvements in Street Pavements," which was discussed by Messrs. Wm. Easby, Jr., S. M. Swaab, J. E. Fulweiler, and others. On motion of Mr. Easby the thanks of the Club were extended to Mr. Tillson.

Regular Meeting, April 20th.—The meeting was called to order by President Hess at 8.30 P. M., with 96 members and visitors in attendance. The minutes of the Business Meeting of April 6th were approved as printed in abstract. Several amendments to the By-laws were presented and read in abstract, and announcement was made that these would come up for discussion at the Regular Meeting of the Club on May 18th.

Mr. H. E. Longwell, Consulting Engineer of the Westinghouse Machine Co., presented the paper of the evening, entitled, "The Gas Producer," which was discussed by Messrs. John C. Trautwine, Jr., Henry Hess, E. M. Nichols, Walter L. Webb, and others. On motion of Mr. E. S. Hutchinson a vote of thanks was extended to Mr. Longwell.

Regular Meeting, May 4th.—The meeting was called to order by President Hess at 8.30 P. M., with 90 members and visitors in attendance. The minutes of the Business Meeting of May 4th were approved as printed in abstract.

Following a report of the Tellers, the following were declared elected to membership: Associate, Clark Judson Hollister; Junior, H. Lawrence Hess and Charles Henry Schaefer.

Mr. Nelson P. Lewis, Chief Engineer, Board of Estimate and Apportionment, New York City, presented the paper of the evening, entitled, "The Engineer in His Relation to the City Plan," which was discussed by Messrs. J. C. Trautwine, Jr., G. S. Webster, B. A. Haldeman, Henry Hess, Robert Schmitz, and E. S. Hutchinson.

On motion of Mr. Webster a vote of thanks was extended to Mr. Lewis.

Business Meeting, May 18th.—The meeting was called to order by President Hess at 8.40 P. M., with 55 members and visitors in attendance. The minutes of the Business Meeting of May 4th were approved as printed in abstract.

The amendments to the By-Laws were presented, and, after discussion, were amended and ordered printed and sent to the members for ballot.

Mr. John C. Trautwine, Jr., presented the papers of the evening, entitled, "The Significance of 'The Middle Third'" and "The Behavior of Cast Zinc Under Compression," which were discussed by Messrs. J. E. Gibson, W. P. Dallet, H. H. Quimby, W. L. Webb, N. W. Akimoff, and Carl Hering. Mr. Trautwine followed these papers with a short talk on his recent visit to Panama.

Business Meeting, June 1, 1912.—The meeting was called to order by President Hess at 8.40 P. M., with 81 members and visitors in attendance.

Following the report of the Tellers, the President declared that the amendments submitted to them for vote were carried and would be incorporated in the By-Laws.

The following gentlemen were declared elected to membership in the Club: Active, William H. Connell, James Benney McCord, and Robert Parker Raynsford; Junior, Theodore W. Pinard, George Franklin Pond, and Alexander Wilson, 3d.

The Board of Directors submitted the following names to constitute a Committee on Nominations for the coming year: Wm. Easby, Jr., Chairman; H. H. Quimby, H. E. Ehlers, W. P. Dallett, E. P. Haines, John C. Trautwine, Jr., and James M. Dodge.

Mr. S. M. Swaab, member, presented the paper of the evening, entitled, "The Queen Lane Filtration Plant," which was discussed by Messrs. N. W. Akimoff, G. S. Cheyney, J. C. Trautwine, Jr., J. A. Vogleson, and Cav. Luigi Luiggi.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Regular Meeting, April 18, 1912.—Present: President Hess, Vice-President Plack, Directors Halstead, Worley, Cooke, Gilpin, Vogleson, Berry, Haldeman, Swaab, the Secretary, and the Treasurer.

The Secretary presented a statement of the financial condition of the Club, which showed a net gain in the income and expense account for the first three months of 1912 of $161.82.

The Treasurer presented a statement of the delinquent accounts, which showed that about one-fourth of the total amount owing on these accounts had been collected as a result of the notice recently put into effect.

Mr. Clayton W. Pike was reinstated as Active Member of the Club as of January 1, 1911.

The resignations of Messrs. C. E. Carpenter and R. R. M. Carpenter were read and accepted. The resignation of Mr. W. H. Johnson, Jr., was accepted.

Mr. Charles F. Mebus was appointed official delegate to attend the meeting of the electors of State College for the election of Trustees.

On recommendation of the various committees, Mr. George F. Pawling and Henry A. Moore were appointed Associate Members of the House Committee, Mr. Frank T. Gucker and Mr. George W. Hyde of the Publicity Committee, and Mr. James Mapes Dodge of the Finance Committee.

The old projecting lantern was, on request of Professor H. E. Ehlers, donated to the Whitney Engineering Society of the University of Pennsylvania.

The sum of $319 was appropriated to the House Committee for the installation of a water-pressure pump to supply the third and fourth floor bath-rooms, provided such apparatus met all the hygienic conditions demanded by the Committee. Mr. J. A. Vogleson was appointed a special member of the House Committee for the consideration of this question.

It was moved and carried that a special Committee, to consist of the President, the Secretary, and the Chairmen of the House, Finance, and Library Committees be authorized to select and appoint a business manager for the Club, at a salary not to exceed $1800 for the first year, plus such bonus as appeared best to the Committee, but not to exceed 20 per cent. of the net increase in income to the Club.

The meeting adjourned upon motion to continue at 6.30 P. M. on Saturday, April 20th.

Adjourned Meeting, April 20, 1912.—Present: President Hess, Vice-Presidents Plack and Mebus, Directors Haldeman, Swaab, Halstead, Vogleson, Kerrick, Gilpin, Worley, the Secretary, and the Treasurer.

The report of the Committee on Amendments to the By-Laws was read, dis-

cussed, and finally adopted, subject to a few minor amendments. It was further ordered that these amendments be presented to the Club at its regular meeting on April 20th.

Regular Meeting, May 16, 1912.—Present: President Hess, Vice-President Mebus, Directors Worley, Develin, Gilpin, Vogleson, Haldeman, Yarnall, the Secretary, and the Treasurer.

A letter from Mr. H. E. Ehlers, thanking us for the lantern, was read.

Reports of the Finance Committee, Membership Committee, and Library Committee were read and approved.

The Chairman of the Library Committee notified the Board that he had appointed Messrs. F. N. Morton and Manton E. Hibbs as additional members of this Committee. The Committee was authorized to expend a sum not exceeding $25 for the use of the library. The House Committee's report was read and approved. Mr. Worley tendered his resignation as Chairman of the House Committee. It was accepted with regret. A vote of thanks was tendered to Mr. Worley for his able services.

The Advertising Committee presented a schedule of rates which was adopted.

The manager's report was read and approved.

The amendments to the By-Laws were discussed.

Adjourned Meeting, June 13, 1912.—Present: President Hess, Vice-Presidents Plack and Mebus, Directors Halstead, Kerrick, Worley, Cooke, Develin, Gilpin, Vogleson, Berry, Haldeman, Swaab, Yarnall, the Secretary and the Treasurer.

The Secretary presented a statement of the financial condition of the Club, which showed a gain in the income and expense account for the first five months of 1912 of $27.14.

The Committees on Finance, Membership, Publication, Library, House, and Publicity did not present formal reports.

The Meetings Committee presented a formal report, stating the principal papers presented during the past season, and a list of papers they hoped to secure for the coming winter.

It was ordered that a condensed copy of the minutes of each Board meeting be sent to each member of the Board.

The Committee on Nominations, appointed by Mr. Hess, as announced in the last notice, consisting of Wm. Easby, Jr., Chairman; H. H. Quimby, H. E. Ehlers, W. P. Dallett, E. P. Haines, J. C. Trautwine, Jr., and James M. Dodge, was ratified.

The question of smoking during Club Meetings was considered, and it was moved and carried that this question be again referred to the Club, with the recommendation of the Board that this smoking be abolished.

A letter from the National Society for the Promotion of Industrial Education was read and referred to the Committee on Public Relations for report.

The report of the manager was presented and approved.

It was moved and carried that a section be added to the rules of the Board of Directors providing for a letter ballot, and that a corrected copy of said rules be sent to each member of the Board.

The election and transfer of members, which was to have been brought before this meeting, was postponed until the following meeting, owing to the absence of a majority of the Committee on Membership.

On motion of Captain Cooke it was moved and carried that a period of at least ten days elapse after the printing of the records of candidates and action upon them by the Membership Committee.

Following a general discussion of house affairs, the meeting adjourned at 9.45 P. M., to continue on call of the chair.

PROCEEDINGS

OF

THE ENGINEERS' CLUB

OF PHILADELPHIA.

ORGANIZED DECEMBER 17, 1877. INCORPORATED JUNE 9, 1892.

NOTE.—The Club, as a body, is not responsible for the statements and opinions advanced in its publications.

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PAPER NO. 1112.

SMOKELESS POWDERS AND EXPLOSIVES FOR MILITARY USE.

ODUS C. HORNEY.
(Visitor.)
Lt. Col., Ord. Dep't, U. S. A.

Presented before the Club, March 2, 1912.

IT has been stated that the development of civilization has kept even pace with the increase and growth of the means of destruction at the disposal of mankind. It was by his superior means of destruction that man conquered the wild beasts of the forest, and it is by the same means that the more highly civilized races have succeeded in imposing their civilization on barbarians and savages.

The stronger the means of offense and defense possessed by any society, the less is the danger of interruption in its growth and progress. This has been true in the past, and is equally true to-day. Only a strong, fearless people, safe in the knowledge that their very strength insures them against attack, can hope to grow and prosper. We may theorize and moralize all we please, but the cold fact remains, that might makes right in the world politics of to-day.

Powders and explosives, the most powerful agents of destruction known to man, have always played an important part in the progress of civilization, and they are, therefore, of great interest to us all.

But our interest in explosives is not confined to their military use. While they were first developed for use in war, they have come to be

one of the absolutely necessary agents in the prosecution of large engineering works.

But for blasting powder, the drilling of tunnels and subways, the quarrying of stone and the mining of ores would be almost incredibly slow and the digging of the Panama Canal or the prosecution of similar enterprises would be all but impossible.

Before describing the more modern explosives, it will be worth while to refer briefly to the old-fashioned gunpowder.

It is now generally believed by those who have studied the subject, that gunpowder was not known before the thirteenth century; although it has been claimed by some that the Chinese and Hindus were familiar with it from early ages. It is probable that gunpowder was developed from Greek fire, and it is practically certain that Berthold Schwartz, of Freiburg, was the first to suggest its use as a propulsive agent in guns. This was about 1313.

This suggestion of Schwartz revolutionized the methods of warfare; but, strange to say, no radical improvement in the quality of powder was made until within the last century.

The first scientific attempt to control the rate of burning of gunpowder was made a little over fifty years ago, by General Rodman, an Ordnance Officer of the United States army. He suggested that since the burning of powder was a surface action, the rate of burning, and therefore the pressure developed in the gun could be controlled by varying the size of the grains. He also advocated the use of perforated grains, but while his suggestions that the size of grains be varied to suit different guns was promptly adopted, perforated grains did not come into use until a number of years afterward.

The use of perforated hexagonal grains, and, later, the use of underburned charcoal in the so-called brown powders, marked the limit of improvement in old-fashioned gunpowder for military use, and in recent years smokeless powder has entirely superseded it as a propelling agent in guns.

It is interesting to note, however, that while smokeless powder did not begin to displace black and brown powders until the beginning of the last decade of the nineteenth century, gun-cotton, which is the base of all modern military powders, was discovered by Dr. Schönbein in 1846. A small quantity of Dr. Schönbein's explosive cotton, as it was then called, was brought to this country in the same year by Mr. William H. Robertson, United States Consul at Bremen, together with Schönbein's formula and specifications for its manufacture.

Captain Alfred Mordecai, of the Ordnance Department, U. S. A., tested this sample and several others made by himself during the latter part of 1846 and the early part of 1847. His tests were conducted for the purpose of determining whether this newly discovered material could be used to replace gunpowder as a propelling charge for guns.

He fired a number of rounds, both from a musket pendulum and from a 24-pdr. cannon pendulum.

The musket pendulum consisted of a metal frame suspended at the top on knife-edges, and carrying at its lower end a service musket barrel, which at that time had a caliber of 0.64 inch. When a charge was fired from this musket barrel the pendulum swung to the rear over a greater or a lesser arc, depending upon the force of recoil. The bullet was fired into a ballistic pendulum, and the angle through which it swung enabled the velocity of the bullet to be calculated.

The 24-pdr. cannon pendulum was similar to the musket pendulum, except that it carried a 24-pdr. gun instead of a musket barrel.

Captain Mordecai fired 20 rounds from the musket pendulum, using charges of various weights between 30 grains and 120 grains, and obtained velocities as high as 1785 feet per second. The cotton was inserted into the barrel loosely and compressed with a rammer. He states his conclusions as follows:

"From these experiments it would seem that the propelling force of a charge of gun-cotton in a musket is a little superior to that of twice its weight of good rifle powder, being nearly equal to a double charge of the best sporting powder.

"It appears that when loaded in the manner here used the gun-cotton will not burn under a great degree of compression, and that the greatest effect is produced when the cotton is pressed into a space equal to about four times that which would be occupied by the same weight of gunpowder or of water. In this respect, however, it is probable that much depends on the quantity of the charge and the manner of preparing it.

"I have fired from a musket charges of gun-cotton prepared in the form of flat discs, just fitting the bore, and only 0.3 inch thick, weighing 26 grains. The effect on a target of pine boards was nearly equal to that of 110 grains of musket powder. But with two of these charges and one ball, the barrel and lock were broken into fragments, although in using the loose cotton I have repeatedly fired charges of 60 grains without any apparent injury to the barrel, in which it occupied a space of about two inches.

"After firing the gun-cotton in a musket barrel, there remains a residuum of water and nitrous acid enough to slightly soil a clean wiping rag."

He fired two rounds from the cannon pendulum, one using a one pound charge, and one using a two pound charge. In commenting on the results, he says: "There was no smoke from the discharge and only a slight acid odor. * * * To those near the gun the report seemed to be sharp and loud; but persons at a distance of 200 or 300 yards represented the sound as being very slight; far less than that made by the charge of four pounds of gunpowder, with which the gun is often fired, and even less than that of a 6-pdr. gun in salute."

In comparing the results with those obtained with gunpowder, he says: "It appears, therefore, that the projectile effect of one pound of gun-cotton in a cannon is equal to that of 2½ pounds of cannon powder, and the effect of two pounds of the former equal to that of four pounds of the latter, being nearly the same proportions as in the musket. From comparing the recoil of the gun pendulum with the vibration of the ballistic pendulum, I conjectured that the explosive or bursting effect of the gun-cotton is much greater in proportion to its propelling force than that of gunpowder."

Later on he made a number of other tests with the musket, to determine whether gun-cotton could be safely used as a substitute for gunpowder, but found that, "In consequence of the quickness and intensity of action of the gun-cotton when ignited, it cannot be used with safety in our present firearms."

While the fact that the explosion of gun-cotton did not cause any smoke was noticed by Captain Mordecai, it does not seem to have impressed him as being a matter of importance, and he does not refer to it in summing up his conclusions at the end of his report.

Nothing further seems to have been done by any one, looking to the use of gun-cotton as a substitute for gunpowder as a propellent, until Captain Edward Schultze of Berlin published a pamphlet in 1865, relating to a nitrocellulose powder which he had invented.

This seems all the more remarkable since Dr. Hartig in 1847 published a pamphlet in which he stated that gun-cotton could be dissolved in acetic ether, and that if the residue left, after the ether had evaporated, were placed in dilute alcohol and afterward dried, it would have the same properties as the original fiber, except that the explosive force would be reduced.

Captain Schultze's powder was made of thin discs of wood, which were bleached, boiled with soda, and finally nitrated in pretty much the same way that cotton is nitrated now-a-days. Later on he used

finely pulped gun-cotton. His patents were purchased by a firm in Austria who manufactured the powder under the name of nitroxylin.

This firm brought out, about 1872, a powder invented by Frederick Volkmann, which was in many respects almost identical with modern nitrocellulose powder. In fact, the description which accompanied his application for a patent showed that Volkmann possessed a knowledge of nitrocellulose powder which in the light of our present knowledge and experience is simply astonishing. He called attention to the fact that his powder was practically smokeless; being the first, apparently, to recognize the advantage of that feature.

The manufacture of Volkmann's powder was continued for about three years, but was suppressed in 1875 by the Austrian Government, because it interfered with the government monopoly in the manufacture of gunpowder. As patents were kept secret in Austria at that time, all knowledge of Volkmann's methods was lost until recent years. In the meanwhile nitrocellulose powder had been reinvented by others.

The term "powder" is frequently used commercially in referring to practically all classes of explosives, whether they are for use as propelling charges or for blasting purposes.

In military use the term "powder" is usually confined to that class of explosives whose rate of burning is relatively slow, and which may be satisfactorily employed as propelling charges for guns. The term "high explosive" is applied to those explosives whose rate of burning or explosion is relatively very high.

The smokeless powders used by the great military powers of the world are of two kinds, commonly designated as nitrocellulose powders and nitroglycerin powders. A great many different kinds of powders have been made, and more or less extensively used, but all of them have practically disappeared from military use except the two just mentioned.

Nitrocellulose powders are composed of nitrocellulose dissolved in ether and alcohol. Only a small percentage of solvent remains after drying, so that they are what their name implies, practically pure nitrocellulose.

The term nitroglycerin powder, on the other hand, is apt to be misleading to those not familiar with the subject, for it is applied to powders whose principal ingredient is nitrocellulose; the nitroglycerin contained in it being usually less than 30 per cent. The well-known English cordite formerly contained nearly 60 per cent. of

nitroglycerin, and was not improperly designated as a nitroglycerin powder; but the present cordite, usually designated as cordite M. D., contains only 30 per cent. of nitroglycerin; 65 per cent. being nitrocellulose and 5 per cent. mineral jelly. Nitrocellulose is, therefore, the principal ingredient of all military powders, and its manufacture is for that reason of particular interest.

Cellulose is not the name of a clearly defined substance, but is a generic term applied to a class of substances which have many chemical and physical characteristics in common. The composition of the celluloses corresponds to the empirical formula $C_6H_{10}O_5$ and early investigators of the cellulose nitrates assumed that that was the real formula. They referred to the highest degree of nitration as trinitrocellulose, and to the next lower degree as dinitrocellulose; but it is now recognized that the real formula is some multiple of the empirical formula.

While the exact formula has not been determined, all known cellulose nitrates can be accounted for satisfactorily by assuming that it is four times the empirical formula. It has not been found possible to introduce more than twelve NO_2 groups into the cellulose molecule, and if this be assumed as $C_{24}H_{40}O_{20}$, the nitrogen would be 14.16 per cent.; but the highest stable nitrate contains only about 13.5 per cent. of nitrogen. In practise it is found that a mixture of different degrees of nitration is obtained, the process of nitration being, apparently, a progressive one.

The cellulose nitrates for military use may be divided, roughly, into three classes: (a) Those of the highest degree of nitration, and which are only partially soluble in ether and alcohol. These are usually referred to as high-grade gun-cotton, or simply as gun-cotton. Military gun-cotton usually contains about 13.3 per cent. of nitrogen. (b) Those containing from about 12.4 to 12.8 per cent. of nitrogen, and which are practically entirely soluble in ether and alcohol. They are usually referred to as pyrocellulose, pyrocollodion, or simply pyro. (c) The lower nitrates which are soluble in ether and alcohol are generally referred to as collodion cottons.

The first two classes are the ones most extensively used, and the only ones used for military purposes in this country; although collodion cottons are mixed with cottons of higher nitration in the manufacture of foreign powders. Material of the first class, or gun-cotton, is used as a bursting charge for mines, torpedoes and projectiles; and pyrocellulose, the second class, is the base of our smokeless powders.

The purest form of natural cellulose is cotton, and more of that material than any other is used in the manufacture of nitrocellulose. The raw cotton used in this country for the manufacture of smokeless powder is almost all what is known as cotton seed hull fiber. This is the very short fiber which still adheres to the cotton seed after it has come from the gin and has passed through the delinting machine. It is of a grayish brown color, and must be bleached and purified before it is fit for use.

The several steps in the process of manufacturing nitrocellulose may be briefly described as follows:

After being put through a picker, which opens up the fiber, the cotton is thoroughly dried, and is then ready for nitration.

Of the several well-known methods of nitration, the pot process was the first to come into general use. In this process a mixture of nitric and sulphuric acid is drawn into an iron or stoneware pot or jar and the cotton immersed in the acid. After the nitration is complete the contents of the pot are poured into a centrifugal wringer, the excess acid wrung out and the gun-cotton then immersed in water.

From this process it was only a step to the so-called centrifugal process, in which the acid is drawn directly into a specially constructed centrifugal. The cotton is then placed in the acid and when nitration is complete, the wringer is started and the acid wrung out as before. These two processes, or modifications or combinations of them, are the ones generally used both in this country and in Europe.

A third method, known as the Thomson Displacement Method, was originated at Waltham Abbey in England, a few years ago, and is the method used at that place and at the Army Powder Factory in this country.

With this process the nitration is conducted in shallow stoneware pans about four feet in diameter and one foot deep. There is a funnel-shaped outlet in the bottom of each pan through which the acid is admitted and afterward drawn off. When the pan has been filled with the required amount of acid, the cotton is dipped into it and a set of stoneware perforated plates is placed on top of the cotton to keep it under the acid. Water is then allowed to flow gently over the top of the plates. When nitration has been completed, the acid is drawn off slowly from the bottom, and water admitted from above. As the level of the acid falls, the water follows and displaces the acid from the cotton, and it is from this action that the process derives its name.

Whichever process is used, the degree of nitration, generally expressed by stating the percentage of nitrogen contained in the nitrocellulose, is controlled by varying the strength and composition of the acid used, the temperature at which the nitration is conducted, and the length of time the cotton is allowed to remain in the acid.

After the nitration of gun-cotton is completed, it is necessary to subject it to very careful and thorough purification, as its keeping qualities are dependent upon the thoroughness with which this purification is carried out. The specifications for powder intended for the United States army or navy require that the nitrocellulose shall be first given five boilings with a change of water after each boiling, the total time of boiling being forty hours.

This is generally referred to as the "preliminary purification." Every step in this and all succeeding operations is closely watched, and the utmost cleanliness and strictest compliance with every detail of the specifications is insisted upon.

Following the preliminary purification the nitrocellulose is finely pulped. The introduction of the practice of pulping gun-cotton during the purification process was one of the most important steps ever taken in the improvement of its manufacture. As cotton fibers are tubular in form, it has been found practically impossible to remove all traces of acid and of unstable products of nitration, until the fibers have been cut up into very short lengths.

After being reduced to a pulp the gun-cotton is given six more boilings, with a change of water after each, followed by ten cold water washings. This is usually referred to as the final purification. It is then subjected to rigid stability tests before acceptance.

Before the purified pyrocellulose is converted into powder it must be freed from water. The moisture is first reduced to about 30 per cent. by means of centrifugal wringers, after which the partially dried material is placed in the cylinder of a hydraulic press and compressed into a compact mass. Alcohol is then forced through the cotton by means of compressed air, thus displacing the water, and leaving the nitrocellulose saturated with alcohol. After the excess of alcohol has been squeezed out of it, the nitrocellulose leaves the dehydrating press in the form of a cylindrical block.

It is next transferred to mixing or kneading machines, where the required amount of ether is added. The best proportions of ether and alcohol have been found to be two parts of ether and one part of alcohol by volume. The amount of this mixed solvent varies in

different cases between about 85 per cent. and 110 per cent. of the weight of nitrocellulose.

From the mixers the material goes to a hydraulic press, in which it is formed into cylindrical blocks about 10 inches in diameter and about 15 inches long. When formed into these blocks, the material ceases to resemble cotton and takes on the general appearance of the finished powder.

These blocks are next transferred to finishing presses from which the powder is extruded in long strings which are passed through a cutter and cut to grains of the required length.

From the cutting machine the powder is taken to the solvent recovery where it is placed in large tanks or chests with tight fitting lids. The vapors of ether and alcohol which are given off when the powder is heated are condensed and collected in an iron tank. This recovered solvent is afterward used in the manufacture of ether. From the solvent recovery the powder is taken to dry houses where it is exposed in bins or trays to a warm, dry atmosphere until sufficiently dry for use. It is then thoroughly blended and packed in air-tight chests for issue.

The manufacture of nitroglycerin powder is similar to the manufacture of nitrocellulose powder, except that high-grade gun-cotton is generally used in place of soluble gun-cotton or pyrocellulose, with acetone as a solvent. The powder used by Italy, generally called ballistite, is an exception to this rule and contains pyrocellulose.

The present nitroglycerin powder is a development from blasting gelatin which was invented by Noble in 1875. He found that if from 7 per cent. to 8 per cent. of nitrocellulose were added to nitroglycerin, a stiff jelly could be produced, and about twelve or fourteen years later he discovered that, by greatly increasing the percentage of nitrocellulose, he could obtain a powder which would burn slowly enough to permit its use in guns. He submitted his invention to the British War Office, but the Committee of Chemists, to whom the matter was referred, modified his powder by substituting gun-cotton for the soluble pyrocellulose in the nitroglycerin, and added mineral jelly in place of camphor. As finally decided upon, the powder contained 58 per cent. of nitroglycerin, 37 per cent. of gun-cotton, and 5 per cent. of mineral jelly. Later on, the percentage of nitroglycerin was reduced to 30 and that of gun-cotton correspondingly increased. This modified form is known as Cordite M. D.

Since the explosion which destroyed the French battleship "Lib-

erte," there have been heated discussions as to the relative merits of nitrocellulose and nitroglycerin powders; one expatriated American going so far as to write a letter to the President of the United States, in which he severely criticized the multiperforated powder used in this country, and charged that the bursting of guns in our service was due to its use. The writer of this letter, Sir Hiram Maxim, enclosed with it an article from "Engineering" of which he is, presumably, the author. This article, appearing, as it did, in a widely known magazine, attracted considerable attention, and if the criticisms of our powder contained in it were based on facts they would be serious indeed.

Whether a smokeless powder is satisfactory or not depends principally upon two things—its chemical composition and its form of grain. Its stability and reliability under the various conditions of storage and use depend upon its chemical composition, the purity of its ingredients and the care with which it is manufactured. Its behavior in the gun, or its shooting qualities, are further affected by its form of grain. The multiperforated form of grain which is used by the United States, and which has been so sharply attacked by Sir Hiram Maxim, was adopted for good and sufficient reasons which will now be explained.

The form of this grain is that of a cylinder having a length about two and a half times its diameter, and pierced with seven holes running through it lengthwise.

The burning of powder being a surface action, it is evident that the rate at which gas is given off is proportional to the burning surface. If a powder is composed of solid grains of any form, these grains will grow smaller as they burn, and the gas will be given off more and more slowly; but with the multiperforated form of grain the area of the seven perforations increases faster than the area of the outside of the grain decreases, so that as a whole the surface increases as the grain burns.

When a charge of smokeless powder is fired in a gun, the pressure behind the projectile increases as the powder burns, and soon becomes great enough to cause the projectile to start forward in the bore. This movement of the projectile increases the volume to be filled with gas, and as the projectile gains in velocity, this volume grows larger at an increasing rate. In order to avoid a drop in pressure the rate at which the powder gives off gas must also increase in the same ratio. The multiperforated form of grain comes nearer than any other form

of grain to accomplishing this result. Moreover, as the maximum pressure which may be permitted in a gun is necessarily limited, it is evident that we want to maintain that maximum as long as possible, in order to obtain a high velocity.

If the burning surface of our powder is relatively small at first, we can use a larger charge than we could otherwise, without danger of overstraining the gun, since the increase in burning surface will come when the projectile is well along in the bore. A higher velocity will, therefore, result.

The "Engineering" article actually cites this progressiveness as an objection to our powder, when, as a matter of fact, it is a strong point in its favor.

A second serious criticism is that the multiperforated grain is structurally weak, and that it is liable to break up in the bore of the gun, thus causing a sudden and unexpected increase in burning surface, and, therefore, in pressure. Experience has shown, conclusively, however, that such breaking up is not to be feared. Large grains of powder have been fired from very short guns in which they were not all consumed, and these partially burned grains have been recovered intact. Some of them have even been fired twice and still recovered intact.

As a matter of fact, a pure nitrocellulose powder, such as that manufactured in this country, is very strong and tough. One of the requirements of the specifications is that when a grain is cut to a length equal to its diameter, it must stand a longitudinal compression of 35 per cent. of its original length before showing cracks on its surface. Our powders meet this requirement easily, but the same could not be said with reference to nitroglycerin powders, which tend to grow brittle with age.

The "Engineering" article which I have referred to, and others which have appeared in this magazine recently, seem to be part of a concerted plan to discredit nitrocellulose powders in general, and those made in the United States in particular. As the opinions recently expressed in these articles are diametrically opposed to the opinions previously expressed in the same magazine, it has been suggested that they were published with the primary object of influencing the placing of powder contracts by South American countries. If it were likely that these articles would have no other effect than that, it would not be worth while to treat them seriously; but they have raised serious

doubts in the minds of many who have read them, as to whether the powders used by the U. S. Army and Navy are what they should be.

The American public naturally wants to know that the powder that is put into the hands of its army and issued to its battleships is, at least, as good as any in use by foreign powers; and that the safety of ships and men is not menaced by its unreliability. I feel, therefore, that those who know the facts should not hesitate to speak of them whenever an opportunity occurs.

The articles in question make four general assertions: 1st. That nitrocellulose powder is inherently less stable than nitroglycerin powder. 2d. That both kinds are more liable to deteriorate when stored in air-tight containers than when exposed to the air. 3d. That the presence of mineral jelly in cordite protects it against dampness, and that air-tight storage cases are, therefore, not necessary, as with nitrocellulose powders. 4th. That the navies which use nitroglycerin powder have had fewer accidents from defective powder than those who use pure nitrocellulose powder.

Strange to say, very little stress is laid upon the one and only important advantage which nitroglycerin powder possesses over nitrocellulose powder; which is this: Nitrocellulose powder is deficient in oxygen, while nitroglycerin powder contains an excess of oxygen. The combustion of the latter is, therefore, perfect and, pound for pound, it is a more powerful powder. A smaller charge of nitroglycerin powder is required to obtain any given velocity than would be required with nitrocellulose powder. The chamber of the gun may, therefore, be made smaller. This means a smaller and lighter gun, and a saving in weight is no small matter on board ship. When you have said this in favor of nitroglycerin powder, however, you have stated almost its only advantage over nitrocellulose powder.

Its temperature of explosion is much higher and it, therefore, causes much more rapid erosion of the gun. As an illustration of the difference between the two powders in this respect, it may be said that actual tests have shown that the accuracy of the caliber .30 service rifle remains as good after 15,000 rounds fired with nitrocellulose powder as after only 3,000 rounds with nitroglycerin powder.

Considering the first of the four general assertions above mentioned, it may be stated with confidence that the weight of evidence is overwhelmingly against the claim that nitrocellulose powder is inherently less stable than nitroglycerin powder. Let me quote

from an article which appeared in "Engineering" magazine itself some years ago:

"The most important considerations in determining the best composition of powders are (a) keeping qualities and safety under normal climatic conditions; (b) capability of highest possible ballistics; (c) regularity in results not to be seriously affected by change of climate, or not to cause excessive erosion. *All* these qualities are secured by the use of the properly manufactured nitrocellulose powder, and *none* can be said to be met by any powder containing nitroglycerin."

The weight of evidence is decidedly in favor of the opinion that both nitrocellulose and nitroglycerin powders keep better in air-tight cases than in cases which are not air-tight; and the claim that because it is made more or less waterproof by the mineral jelly which it contains, cordite may be stored in open cases, loses its force. As a matter of fact, British naval regulations require that cordite charges shall be kept in sealed cases, and lay great stress on this requirement.

The statement that the navies using nitrocellulose powders have suffered more from accidents due to defective powder than those which use nitroglycerin powder, is not supported by facts. Four vessels have been destroyed by explosions believed to be due to bad powder. The Aquidaban, the Jena, the Mikasa, and the Liberte. The first and third carried cordite, and the second and fourth nitrocellulose powder. Other accidents in the magazines of the British vessels Revenge and Fox, due to decomposing cordite, have been commented upon by "Engineering" itself. Although exact information is difficult to obtain, it is believed that accidents due to bad nitroglycerin powders have been more numerous than those due to bad nitrocellulose powders.

It is not claimed by any one, so far as I am aware, that nitrocellulose powder remains perfectly stable under all conditions of storage for an indefinite length of time. Under the action of heat and moisture both kinds of powder will deteriorate; but it may be added that while nitrocellulose powder will in general decompose slowly and finally lose its explosive properties, nitroglycerin powder is more apt to explode. Under extremes of heat and cold nitroglycerin powder is liable to sweat; that is, nitroglycerin will exude and collect on the surface. When this occurs, the powder is very dangerous to handle. Finally, it may be added, that while our older nitrocellulose powders have shown very satisfactory stability under

ordinary conditions of storage, our newer powders, that is to say, those which have been manufactured since 1908, are even more stable, a stabilizer having been used since that date.

It may, therefore, be confidently asserted that better powder is not made anywhere in the world than in the United States for the army and navy; and nowhere is greater care taken to secure a uniformly high grade product.

It is not to be supposed, however, that our search for improvements has ceased. Like the powder makers of other countries, we are now seeking a flashless powder.

The flash from a gun firing smokeless powder is intensely bright and this flash is of great assistance in locating the position of an enemy's guns, especially during night firing. A demand has, therefore, grown up for a flashless or flameless powder.

The intensity of the flame from smokeless powder is due principally to its high temperature of explosion, which causes the particles of residue to become incandescent. The addition of some ingredient to cool the flame is, therefore, required if a flameless powder is to be produced. Sodium bicarbonate was the first substance suggested. It cools the flame by losing its water of crystallization and carbon dioxide. Oils, soaps, etc., have also been proposed.

No flashless powder has been adopted in any service so far as I know, although a number have been offered for test; but I believe it is only a question of time, and a short time at that, before its use will be general.

With the silencer already an accomplished fact, success in our search for a flashless powder will enable artillery to bombard an enemy without being seen, without smoke, flame or noise.

Turning now from the consideration of powders to high explosives, it will be well to explain some of the more important requirements that a satisfactory military explosive must fulfil. As stated before, the distinction between a powder and a high explosive is based upon the rate of explosion. Powders burn, and the rate of burning can be controlled; but the decomposition of a high explosive seems to take place throughout its entire mass almost at the same time.

Materials which explode with great violence are said to "detonate" or to give a high order of explosion; while those, like gunpowder or smokeless powder, are said to give a low order of explosion. Some explosives like the fulminates, or nitroglycerin, always detonate; on the other hand, smokeless powder always gives an explosion of a low

order; while the picrates and similar nitro-compounds may detonate or may give a low order of explosion, depending upon the method of ignition.

On first thought, it might appear to one not familiar with the subject that explosives which satisfactorily meet the requirements of commercial use would be equally satisfactory for military purposes, but such is not always the case. In some respects the conditions to be met in commercial use are the same as in the military service, but in others they are diametrically opposed. For example, if an explosive is to be used in mining or in blasting a tunnel, it must not give off noxious gases upon explosion, but if it is to be used as the bursting charge of a projectile, the fact that it gives off poisonous or asphyxiating gases is a point in its favor. And again, many explosives which may be considered reasonably safe for commercial use would be dangerous to fire from a gun.

The principle uses for high explosives in the military service are for bursting charges of projectiles, for submarine and land mines, for torpedoes, for fuses, and for demolition purposes.

There are certain general conditions which explosives must fulfil to suit them for military use of any kind. They must be reasonably safe to manufacture and to handle. The supply must be ample and it must be possible to procure them in reasonable quantities at short notice. They must have the maximum strength consistent with other conditions. They must be stable. This is particularly true in the case of those explosives which are to be held in reserve for use in case of emergency, and for those which have been filled into projectiles and which are, therefore, so placed that they cannot be periodically inspected. They must be reasonably non-hygroscopic, that is to say, they must not absorb such a quantity of moisture during storage or while being handled as will interfere with their explosive properties.

For demolition purposes nearly any kind of an explosive can be used in an emergency, but to be well suited for this purpose, an explosive should be safe to handle and transport in wagon trains or pack trains. It should be easy to detonate with the ordinary primer or commercial detonator. It should be, preferably, of such a nature that it may be made up in advance into the form of cartridges. A plastic material is particularly well suited for such use.

For torpedoes and mines the special requirements are comparatively few. One of the most important is that the explosive used shall

not be hygroscopic or else its explosion shall not be affected by the presence of moisture. Wet gun-cotton, besides being one of the safest of all high explosives, is particularly well suited for use in damp situations. Being already wet, a leak in the walls of a mine would not be of serious moment. The greatest drawback to the use of wet gun-cotton is the fact that it requires a priming charge of dry gun-cotton to properly detonate it, and dry gun-cotton is one of the most dangerous explosives we have to handle. In spite of this drawback, however, gun-cotton has been, and still is very largely used for mines and torpedoes, although other explosives are pressing for recognition. One of the most promising of these is trinitrotoluol, which is absolutely non-hygroscopic, is safe to handle, and is easy to detonate. The supply of raw material for its manufacture, toluol, is practically unlimited; and like the other nitro-compounds of this class, it remains stable for an indefinite length of time.

When we come to the selection of an explosive for projectiles, the greatest difficulty is encountered. This very difficulty has seemed to act, however, as a spur to inventors, and the number of explosives that have been offered for test in the military service is almost countless. Potassium chlorate, because of the large amount of oxygen which it contains and the readiness with which this oxygen is given off, seems to have a particular fascination for inventors, and combinations of potassium chlorate with some carbonaceous matter are patented with tiresome regularity. A great many of these potassium chlorate mixtures have been tested, but few of them have given promising results. The chlorate is liable to be dissolved out, if the explosive becomes damp, and may recrystallize and render the explosive very sensitive to shock.

Among the most important of the explosives which have been tested in this country at various times for use in filling projectiles may be mentioned nitroglycerin, blasting gelatin, picric acid, emmensite, joveite, maximite, trinitrotoluol, trinitrobenzol and wet gun-cotton.

The extreme sensitiveness of nitroglycerin renders its use absolutely impracticable, and blasting gelatin is also exceedingly dangerous, due to the large percentage of nitroglycerin which it contains.

In recent years picric acid has been used in some form or other, or in combination with some other material by practically all large military powers as a bursting charge for projectiles. It is interesting to note in this connection that the explosive properties of picric acid

were well known to Prof. Sprengel as early as 1873, and were spoken of by him in a public lecture about that time.

One of the greatest objections to picric acid is its high melting point, so that the filling of projectiles with melted picric acid is attended with some danger. Taking advantage of the fact that the melting point of a mixture of two substances is usually lower than the melting point of either of the constituent substances, picric acid has been mixed with nitronaphthalene, nitrotoluol, nitrobenzol, camphor, etc., and these mixtures have been used under various names, as lyddite, ecrasite, melinite, shimose, maximite, etc.

An explosive intended for bursting charges for projectiles must from the very nature of its use be very insensitive. It must not only withstand the shock of firing, since a premature explosion would almost certainly burst the gun, but it must not explode under the very much greater shock of impact against an armor plate. It should be possible to fire a projectile filled with high explosive through an armor plate, and, by means of a delayed action fuse, cause the explosion to take place in rear of the plate.

With the great insensitiveness which this demands, is coupled the requirement that the explosive must be capable of being completely and certainly detonated by the service fuse. It may be easily understood, therefore, that the number of high explosives which fulfil these requirements is quite limited.

Fine-grained black powder was formerly the only explosive used for filling projectiles, but although it was perfectly stable and did not deteriorate in storage it was very sensitive to shock and friction, and when other explosives of much greater power became available, it was superseded by them, and is now little used.

The question as to the proper means to use in the attack of an armored vessel is a complicated one, involving a study of projectiles, explosives, and fuses. Artillerists are not agreed as to whether it is better to depend upon projectiles carrying heavy charges of explosives, and fitted with quick acting fuses which burst upon impact with armor, or to use a stronger projectile carrying a smaller bursting charge, and fitted with a delayed action fuse which will cause the projectile to burst inside the vessel, after it has penetrated the armor. The destruction caused by a projectile bursting in the hold of a vessel is many times as great as that caused by an outside explosion against the face of the armor; but the difficulty of securing penetration at long range and at oblique impact is very great. Even second-

ary armor overmatches a heavy projectile if the striking angle be very oblique. It is for this reason that some artillerists favor the use of comparatively weak projectiles with large cavities holding heavy charges of high explosives, and fitted with quick acting fuses, which cause the projectiles to explode upon impact.

If a projectile is made strong enough to penetrate heavy armor, its walls must be thick, and the bursting charge comparatively small. If such a projectile, fitted with a delayed action fuse, strike an armor plate at a very oblique angle, it will glance from the plate, and, because of the delayed action of the fuse, the explosion of the charge will take place too late to reinforce the blow of the projectile. The effect on the armor will, therefore, be no greater than it would have been if a solid shot had been used.

The effects produced by the two methods of attack: First, the projectile carrying a charge of blasting gelatin, the most powerful of explosives. The inventor, who proposed the use of this very sensitive explosive, devised a special form of shell in which the charge of gelatin was divided into a number of sections by diaphragms in order to reduce the shock on the explosive. His shell was longer than an ordinary armor piercing shell and carried a large charge of explosive. He made no effort to secure penetration, but hoped to be able to smash the armor plate and stave in the side of the vessel by the force of the explosion.

The first round was fired from a 12-inch gun at an angle of impact of 45° C. The plate was carried some distance along the side of the butt, but was unbroken. The wooden support was repaired and the plate set up in its original position.

A second projectile filled with blasting gelatin was then suspended against the plate and exploded electrically, without material injury to the plate.

It will be interesting to compare these results with those obtained by firing a service 12-inch shell against an armor plate, and causing it to explode in rear of the plate.

Later on, a third projectile charged with over 175 pounds of blasting gelatin was fired against a target representing a section of a battleship. The impact was normal to the armor plate. A slight depression was made in the face of the plate, and the entire structure was moved to the rear about four inches; otherwise the target was not damaged.

Two other rounds were fired with shells containing blasting gelatin, but the second one burst in the gun.

Three eighteen-inch projectiles, each carrying 2500-pound charge of gun-cotton, were fired against a target representing a section of a battleship, and faced with armor plate 11½ inches thick. The first round, fired at the center of the plate, produced a slight indentation, and moved the whole structure a few inches to the rear. The cellular structure supporting the plate was somewhat buckled, but no other damage was produced.

The second round, fired at the center of the right half of the armor plate, caused the plate to move slightly to the right and about three feet to the rear. The plate was dished horizontally and the cellular structure was further damaged and rivets sheared. The third round, fired at the center of the left hand of the plate, caused the plate to crack vertically through the point of impact of round two, and also produced a slight indentation of the plate.

Another target of exactly the same construction was then tested, using service projectiles.

A 12-inch armor piercing shot, carrying about 20 pounds of explosive, was first fired through the center of the plate and detonated immediately in rear of it. It destroyed much of the cellular structure and backing. A 12-inch armor piercing shot was then fired at the center of the right half of the plate. It detonated before it had passed entirely through the plate, but wrecked the right half of the plate, and badly damaged the cellular structure in rear. A 12-inch armor piercing shell was fired at the left half of the plate and detonated after penetrating about 6 inches. The lower left hand part of the plate was broken into a number of pieces, and the target wrecked.

Other much more extensive and elaborate tests have been conducted to determine the effects of projectiles fired under different conditions, and at various angles of impact, against targets representing sections of battleships and armored cruisers; but while the results were of great technical value, they would not be of as much general interest to the members of this society as those already described.

It will be seen from even the few tests which I have mentioned that we cannot hope to destroy heavy armor by means of outside explosion alone. At least partial penetration must be secured unless the projectile greatly overmatches the plate in size, weight and velocity.

At long range and oblique impact, penetration is difficult to secure,

and if the angle of impact be very oblique, even secondary armor will resist penetration. This secondary armor can be broken, however, by the explosion of heavy charges against it, so we see that there is a field for a projectile of comparatively small penetrative power, but carrying a heavy charge of explosive and fitted with a quick acting fuse, as well as for the very strong projectile intended to penetrate armor and explode behind it.

If a projectile falls a little short and explodes under water, a large charge of explosive is of course very desirable.

DISCUSSION.

E. M. NICHOLS: What interests me most is how you time the fuses. There must be a very short interval between the time of the impact, which starts the burning of the fuse, and the explosion.

A. Yes, it is merely a matter of experiment—of trial and error—until the right length of burning time is secured.

MR. NICHOLS: That struck me as the most important part.

A. The most difficult thing to secure is uniform burning of a time fuse intended to cause the projectile to burst in the rear or in front of an attacking line. These fuses may be set to explode at any time after leaving the muzzle of the gun. In the case of the field gun, twenty-eight seconds is the maximum burning time.

SECRETARY (referring to sample of powder exhibited): Has this grain actually been fired twice?

A. Yes, it has been fired from a field gun twice; it was fired from a three-inch field gun which is relatively very short; the velocity with which it is thrown from the muzzle puts it out and stops its burning.

ROBERT SCHMITZ: I would like to ask if experiments have been made with different size grains of powder in place of perforated powder, for the purpose of regulating the supply of the burning powder, the idea being that the small grain is burned first, and the larger grain, having a certain amount of surface, the burning would be regulated that way.

A. Yes, that has been tried. It can be shown mathematically that a mixture of grains of different sizes gives results comparable to cubical grains. It must be remembered that the initial pressure cannot be too high in comparison with the average pressure.

MR. SCHMITZ: If the grains were so placed that the small particles could be burned last, they would be burned when the volume was most needed.

A. I do not think that has ever been tried.

MR. SCHMITZ: If it was enclosed, say a smaller box inside a larger box, so that the smaller particles burning later would increase the volume of gas; that was my idea. Is the silk bag actually destroyed?

A. Yes, the silk bag is actually destroyed, but instead of being burned (it has not sufficient length of time to burn), it is simply disintegrated by the explosion of the powder.

CHAIRMAN: Here is a powder with square holes in it: what is that?

A. It illustrates an attempt to do something that this gentleman here was asking about. The idea is to make the initial burning surface very large, the object being to reach the maximum pressure as soon as possible. This is followed by a sudden drop in the burning surface just before the maximum pressure is reached; and from that time on the grain will burn with a gradually increasing surface.

Carl Hering: What is the effective range of the 16 inch gun?

A. Mounted on a carriage permitting an elevation of 45 degrees, it is calculated that it would give a range of between 20 and 21 miles.

Mr. Hering: Is there any object in building a gun to shoot as far as that?

A. That is simply an illustration of the power we are trying to obtain.

Chairman: Over a shorter range there is a more direct trajectory?

A. The larger and heavier the projectile, the less the effect of air resistance is in proportion to any given velocity and the greater the range.

A Member: I would like to ask what the practical elevation is?

A. For heavy guns the elevation is 15 to 20 degrees, for howitzers, or mortars up to 70 degrees, and for balloon guns up to 90 degrees.

Mr. Casgarten: I think mention was made of using smokeless powder and a silencer; I think that is not quite correct. According to my experience, the noise of shooting combines two noises, one produced by the gases, and the other produced by the bullet as it flies through the air, and neither can be avoided by the silencer; is that not correct?

A. Quite correct.

Mr. Hering: You spoke of firing at an angle of 90 degrees; how do you protect the gunners?

A. No projectile comes down as it goes up; that is, not at the same angle. The carriage *permits* firing at an angle of 90 degrees, but it is not likely that the gun would be fired at that angle.

PAPER No. 1113.

THE QUEEN LANE FILTRATION PLANT.

S. M. SWAAB.
(Active Member.)

Read June 1, 1912.

INTRODUCTION.

THE subject of the water supply of the city of Philadelphia has received considerable attention from The Engineers' Club, and in our Proceedings are several papers descriptive of the works. It is not my intention, other than in a general way, to speak of the Water Supply *per se;* but rather to describe in detail, historically and otherwise, the construction of the last unit of the Filtration System, begun in the year 1901, and prosecuted during about ten years of the period intervening between that date and the present.

This paper contains a historical sketch of the Queen Lane Filter Project, as well as a description of the construction and method of operation of the Queen Lane Filter Plant of the Philadelphia Water Supply, and also a brief outline of the process of the purification of water by slow sand filtration and of the evolution of that process.

HISTORICAL.

Benjamin Franklin it was, I believe, who first publicly called the attention of the citizens of Philadelphia to the very important subject of obtaining water for the city from some other source than the wells then universally used, urging that the affiictions from the ravages of contagious disease rendered it necessary that a more copious supply of water should be procured to insure the health, comfort and preservation of the citizens.

This was about the year 1793 or 1794, just after the city had been visited by the yellow fever; and in Franklin's will, dated June 23d, 1789, is the following clause: "And having considered that the covering of the ground plot of the city with buildings and pavements, which carry off most of the rain, and prevent its soaking into the earth, and

renewing and purifying the springs, whence the water of the wells must gradually grow worse, and in time be unfit for use, as I find has happened in all old cities, I recommend that, at the end of the first hundred years, if not done before, the Corporation of the City employ a part of the 100,000 pounds in bringing by pipes, the water of the Wissahickon Creek into the town, so as to supply the inhabitants, which I apprehend may be done without great difficulty, the level of that Creek being above that of the city, and may be made higher by a dam. I also recommend making the Schuylkill completely navigable."

Less than one hundred years after the date of Franklin's will a commission reported on a scheme for procuring water for the city from the upper Delaware. The recommendations of this report were never acted on and about one hundred and ten years after the date of his will, the commission appointed by Mayor Ashbridge recommended the filtering of the water of the Delaware and Schuylkill Rivers within the city limits, which, with the completion of the work described in this paper, has been entirely accomplished with all of the beneficent results which were predicted.

The site now occupied by the Queen Lane Filter Plant and Reservoir was occupied in Revolutionary times by Washington as a military camp. A granite obelisk at the northerly corner of the plant has the following inscription:

THE MAIN CONTINENTAL ARMY COMMANDED BY
GEN. GEORGE WASHINGTON ENCAMPED ON THIS
AND ADJACENT GROUND FROM AUG. 1 TO AUG. 8
AND FROM SEP. 12 TO SEP. 14, 1777, BEFORE
AND IMMEDIATELY AFTER THE BATTLE OF
BRANDYWINE.
ERECTED IN 1895
BY THE PENNA. SOCIETY OF SONS OF THE
REVOLUTION TO PERPETUATE THE MEMORY OF
THE ENCAMPMENT.

History of the Queen Lane Filter Project.

On September 1st, 1896, Mr. Allen Hazen, in a report to the Woman's Health Protective Association, entitled, "A Practical Plan for Sand Filtration in Philadelphia," proposed as part of a comprehensive scheme a filter plant of an average daily capacity of 26,000,000 gallons and of a maximum of 39,000,000 gallons, occupying 40 acres west of Wissahickon Avenue between a point south of School Lane and Queen Street, immediately north of the

Queen Lane Reservoir. The land alone was estimated to cost $200,000.

Mr. John C. Trautwine, Jr., Chief of the Bureau of Water, on September 9th, 1908, submitted to Mr. Thomas M. Thompson,

Fig. 1.—Power House Tank Tower, Preliminary Filters and Intake Gate House, Queen Lane Filter Plant.

Director of the Department of Public Works of Philadelphia, a report on "Filtration, with Plans and Estimates of Costs, etc.," in which he proposed a rapid or mechanical filter plant located on private property north of Thirty-first and Queen Streets for the Queen Lane

section. The capacity of the plant, as proposed, was 30,000,000 gallons daily.

In a paper by Mr. John W. Ledoux, of January, 1899, "Concerning the Water Supply Problem of Philadelphia," he suggests as part of a scheme of slow sand filtration the use of the north compartment of the Queen Lane Reservoir, in which he proposed to build 19 acres of filter beds; and he also suggests the construction of a masonry dividing wall in the south compartment of the reservoir, the westerly part of which was to be retained in service as a sedimentation basin, and the easterly section as a filtered water basin.

On September 15th, 1899, a report was submitted to Mayor Samuel H. Ashbridge by Messrs. Rudolph Hering, Joseph M. Wilson and Samuel M. Gray, a commission which he had previously appointed in accordance with a resolution of City Councils of April 20th, 1899, for the purpose of investigating and reporting on a general scheme for the "Extension and Improvement of the Water Supply." The recommendations of this commission, as far as Queen Lane was concerned, were to purchase for the site of the plant the Smith property on the north side of Queen Street west of Wissahickon Avenue, on which they proposed to build 27 filters, each of an area of about three-fourths of an acre, and to subdivide the South Basin of the reservoir into two compartments, the easterly one of which was to be used as a filtered water basin, exactly as in the scheme of Mr. John W. Ledoux above outlined. The plant was to have a capacity of 58,000,000 gallons daily, and in the estimate there is set aside the sum of $310,000 for the purchase of the site. Subsequent to the publication of the commission's report, and after the actual construction of the works now approaching completion was started, many parts of the general scheme were recast, many details changed, the entire scheme amended by the introduction of preliminary treatment of the water, and the distribution districts in many cases enlarged or altered. One of the changes proposed by Mr. John W. Hill, then Chief Engineer of the Bureau of Filtration, was to abandon the project of filtration at the Queen Lane site, and to build certain filters at the Torresdale Filter Plant, which were to be known as the Queen Lane Contingent. The water treated in these filters was to be pumped through the Queen Lane distribution districts from the Lardner's Point pumping station by the pumps which are at present in the Queen Lane pumping station on the Schuylkill, which station it was proposed to abandon. The pumps were to have been rebuilt

and modernized and re-erected at Lardner's Point. By this scheme, it may be observed, it was intended to supply the Queen Lane District with Delaware River water. The idea of building the filters at Queen Lane was revived in 1905–1906.

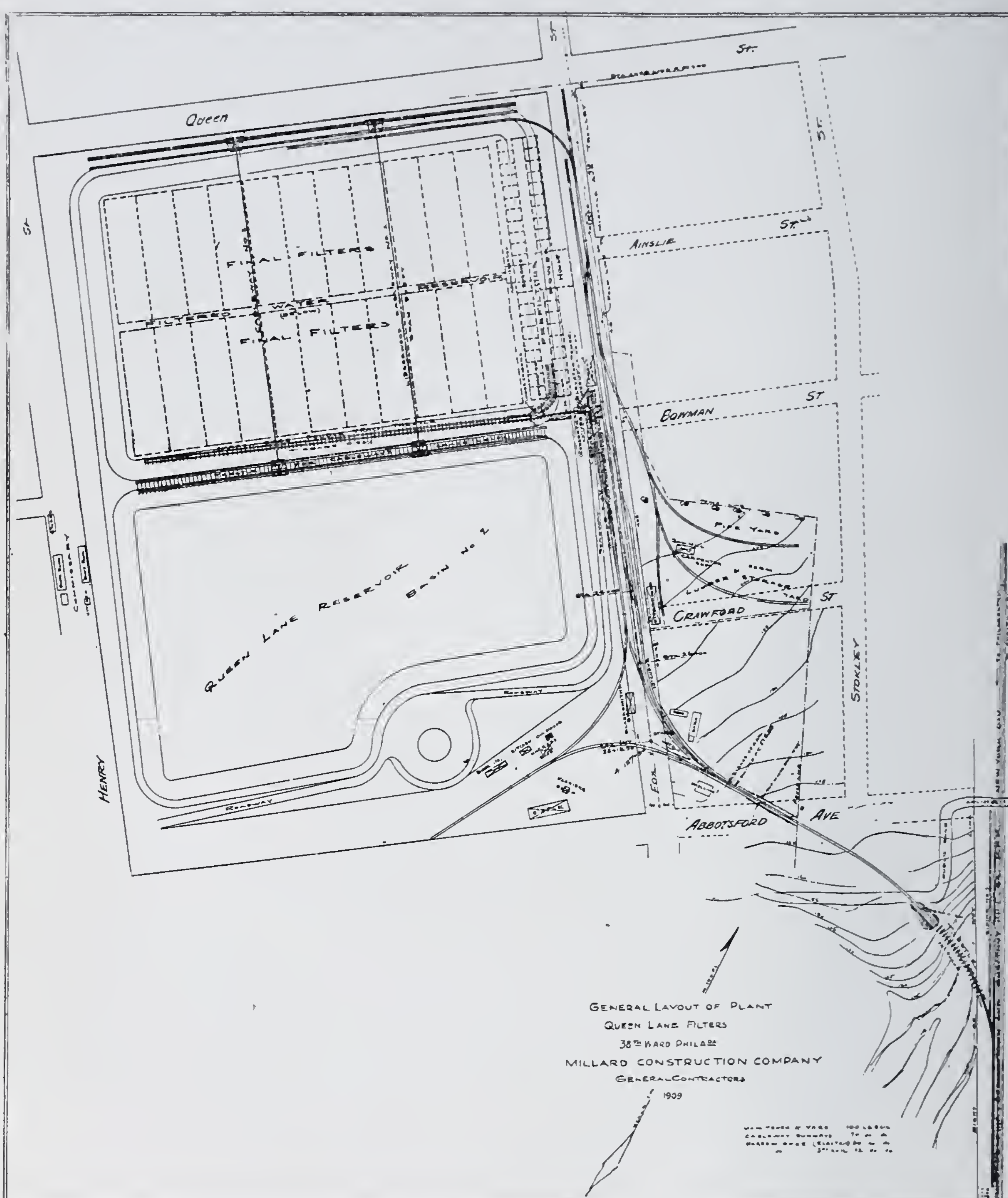


FIG. 2.

It was discovered as a result of the Pitometer Survey that the filter plant, as constructed, was inadequate, and extensions in several directions were considered advisable. As a matter of fact, however,

in the more than half decade which had elapsed between the time of the Ashbridge Commission's report, and the date at which further extension was considered desirable, the population of the city had increased, and, with this, the normal use of the water for domestic purposes. It should be observed also that all of the recommendations of that report had not yet been fulfilled, nor had the subsequent changes suggested by Hill, notably the Torresdale Preliminary Filters, been built. The writer, then First Assistant Engineer in the Bureau of Filtration of the Department of Public Works, suggested to demolish, in whole or in part, the banks of the north basin of the Queen Lane Reservoir, and to build the filter plant within the lines of the banks, superimposed on the filtered water basin, to be built on the floor of the reservoir, using filters so designed as to permit the use of the Blaisdell or other traveling machine for washing the sand within the filters, thus permitting a substantial reduction in the area of the courts, etc. The necessary computations and estimates and also sketches and tentative plans for the project were made at that time, and the work has actually been built on these lines. Whatever merit there may be in the detailed designs of the present plant is due to Mr. Dunlap, Chief of the Bureau of Water, by whose organization the working plans were made and carried into execution. The method of construction employed is a novel, interesting and quite economical one, so to speak,—a different method from that used on any of the previous work of a similar character in this country and elsewhere. In numerous mechanical filter plants this double-decked arrangement exists. On a large scale, however, it did not, at the time this work was first projected, exist on any work of greater magnitude than the Montmartre Reservoir, Paris, built in 1888–89, and which covers 24,800 square feet, or about 0.6 acre, and has a capacity of 2,900,000 gallons. This reservoir is four stories high, each of the three upper stories being made to supply water to a different section at a different pressure, the lower compartment being utilized as a pipe gallery and for seepage. When it is considered that the floor area of the filtered water reservoir at Queen Lane covers upward of 17 acres, the magnitude of this feature of the work is apparent.

General Description of the Work.

The Queen Lane Filter Plant of the Philadelphia Water Supply is situated on the site of the north basin of the Queen Lane Reservoir,

which was demolished in order to provide the necessary area. The plant covers an area of, approximately, 25 acres, and consists of 22 rectangular covered filter beds, each 344.5 by 96 feet, or three-fourths of an acre in extent, built over a filtered water basin with a floor area of, approximately, 17 acres, and a capacity of 50,000,000 gallons to the flow line. This basin is divided into two compartments by a solid masonry wall. A 48-inch hand-operated sluice gate connects these two compartments. The filters are ranged on the two sides of a

Fig. 3.—Groined Arch Vaulting of Filtered Water Basin Roof and Filter Floor.

covered gallery below a central court containing the supply conduit and also the gate houses for regulating the flow to and from the filters, the necessary drains, etc.

At the easterly end of the plant, situated on a plateau formed by practically cutting down the original east bank of the reservoir, and filling in between this bank and a retaining wall, which forms the easterly wall of the adjacent filters, are located the preliminary or roughing filters, the prefilters, as they are locally called. They are 40 in number, each 32 by 40 feet, or about 0.03 acre in area, and are

used for the rapid filtering of the settled water which is drawn from the south basin of the old reservoir, which is to be retained as a sedimentation basin in connection with the new works. The capacity of this basin is 177,000,000 gallons.

The water is drawn off the reservoir either through a gate house situated at the easterly end of the present division bank of the old reservoir (which remains intact and becomes the north bank of the converted sedimentation basin), through a steel-riveted pipe, 84 inches in diameter, or through a 48-inch pipe connection from the inlet pool of the reservoir, and is conducted to the prefilters. This latter connection will be used when it becomes necessary to clean or repair the reservoir, or may be used if it becomes expedient to cut out the sedimentation process. From the prefilters the effluent passes through a rectangular reinforced concrete conduit to a similar conduit which is situated in the covered gallery between the filters, the roof of the latter conduit forming the roadway of the central court. The prefilters are completely covered by a house with a central platform on which is located the operating mechanism and the instruments for observing and regulating the flow. A 48-inch cast-iron by-pass is also provided for conducting the settled water from the sedimentation basin to the slow sand filters, so as to cut out the rapid filtering process when it may be found to be physically and economically desirable.

A power-house and a tank-house, containing a 200,000 gallon steel tank, are provided with the necessary machinery for supplying water and air under pressure for periodically washing the sand beds in both the slow and rapid filters.

An office or administration building, overlooking the plant, is provided for the officials, and contains also the necessary quarters for the workmen employed in the operation of the plant.

Two riveted steel pipes, each 60 inches in diameter, connect the new filtered water basin with the present distributing system, passing under the administration building, the tank-house, the prefilters and power-house, in which is situated a valve chamber for controlling the flow from the basin.

The filter plant has a capacity of 70,000,000 gallons per twenty-four hours, and is intended to supply the high levels of the old Queen Lane district and furnish a possible surplus to meet some of the increasing demands in other localities.

Operation of the Plant.

The operation of the plant is quite simple. River water is admitted to the filters above the sand layer by opening a hand-operated gate-valve connecting with the conduit in the court between the filters. It passes through the sand layer and into the gravel below, in which are laid 6-inch terra-cotta pipe drains with open joints, transverse to the long axis of the filter bed, and 16 feet on centers connecting with the main collector, which extends from one end of the filter to the

Fig. 4.—Roof Filtered Water Basin and Arched Dividing Wall.

other, and which terminates in one or other of the gate houses heretofore mentioned. The flow from the main collector is controlled by a hand-operated circular sluice gate which admits the water to a well under the gate houses from which it passes through a submerged rectangular orifice into the filtered water reservoir below, the rate of filtration being controlled by increasing or decreasing the head on the orifice at will by the operation of the sluice gate. A pipe line laid under the influent conduit in the central court connects the individual gate houses and serves to lead filtered water from a filter bed

which is operating to a bed which has been out of service for cleaning, so as to fill the bed from below through the main collector to above the sand level, which is the usual practice in starting a filter.

In the gate houses on the central court are valves for draining the beds. The valves conduct the water to a passage in the pipe galleries either side of the influent conduit under the central court, and these connect with the sewers built in conjunction with the plant. At the rear end of each filter bed is situated a chamber containing a hand-

Fig. 5.—Slow Sand Filters, Partition and Dividing Walls.

operated sluice gate, to be used in draining the beds, in case the so-called Brooklyn method of cleaning the filters is used. Each filter is subdivided into three compartments by longitudinal arched walls from end to end, the walls between the individual filters being solid. In each alternate wall is built a channel, the outlet of which is connected with the drains which parallel the plant immediately north and south of it, for use in connection with the Blaisdell or other sand-washing machine. In the pipe galleries are pressure pipes connected with the pumps for supplying water under pressure to the

ejectors, or the Nichols machine or other type of sand-washing apparatus in the beds where the sand is washed practically in place.

The prefilters, 19 on one side and 21 on the other, are separated by the pipe gallery containing the influent or raw water conduit as well as the effluent conduit, one on the other in the order named. In the space between these conduits and the filters are placed the valves and piping and other apparatus for admitting and drawing off the water. The top of the raw water conduit extended to the filter walls, covering the piping and valves, constitutes the operating floor, and on this are placed the tables for controlling the operation of the valves and the instruments for recording the rate and loss of head in the filters, etc.

The filter floor consists of a number of small channels transverse to the main collector, which terminates in a covered collecting well formed by dropping the bottom of the collector next to the front wall of the filters. These channels are covered with a reinforced concrete floor two inches thick, made in slabs, in which are inserted numerous perforated brass strainers for admitting the prefiltered water to the channels below, from which it flows by gravity through the main collector and collector well to the effluent conduit through a balanced valve, which maintains the height of water above the sand by automatically raising a partially submerged copper float when the water attains a pre-determined height. The entrance of the raw water to the filters is controlled or regulated by a submerged circular orifice on the end of the inlet pipe. All of the valves and sluice gates in the prefilters are operated from individual operating tables, placed on the gallery floor in front of the several filters. All of these gates are fitted with hydraulic cylinders in which the pistons are raised or lowered by admitting water under a pressure of about 60 pounds per square inch. Each of these tables is connected with the pressure pipes which are supported on brackets on the sides of the influent conduit. By throwing a brass lever to one side or the other, water under pressure can be admitted above or below the water pistons which raise or lower the gates. From each table is controlled the raw water supply, the effluent, the wash water, the waste water (water soiled in the washing process), and the air used in the process of washing. To a steel tank containing about 200,000 gallons, located in the tank tower, is attached a pipe which is suspended from the roof over the operating gallery and is connected with each of the filters, supplying water under pressure for washing the sand bed. In the process of washing,

the current is reversed and the water is admitted to the underdrains, from which it rises through the sand bed. In addition to this, air under a pressure of about four pounds per square inch is applied through a rather extensive system of supply pipes and air manifolds, to assist in breaking up the sand bed. The water, as it rises above the sand, is carried off by a system of wrought iron troughs communicating with the wash water gullet which is built in the center of each filter. The end of this gullet has a sluice gate attached to it, operated from the table, and discharging into the adjacent pipe gullet, from which the dirty water is conducted to the sewer.

A system of heating, using exhaust steam, is provided for maintaining a working temperature within the prefilter gallery. The radiators are attached to the filter walls and the steam pipes are supported on the same brackets which support the piping for the hydraulic system.

The filtering material in the slow sand or final filters consists of 26 inches of sand of a least effective size of 030 mm., and a greatest effective size of 0.38 mm., with an average of about 0.35 mm. and a least uniformity coefficient of 1.70, and a greatest uniformity coefficient of 2.70. The sand is placed on top of a layer of graded gravel 16 inches in thickness, the largest size of which is about 3 inches and the smallest size about ⅛ inch.

The specifications for the prefilter sand require 12 inches of sand of a least effective size of 0.80 mm. and a greatest effective size of 1.00 mm., with a least uniformity coefficient of 1.50 and a greatest uniformity coefficient of 1.75. The sand is supported on a bed of graded gravel 15 inches in thickness.

In the intake gate house, through which the water is admitted to the preliminary filters from the reservoir, are located the screens and also three hydraulically operated, rectangular sluice gates, each of 12 square feet area (full opening), as well as the raw water controller for maintaining the level of the water back of the gates. The pistons in the cylinders operating these gates are controlled by a pilot valve which is opened and closed (and this admits water under pressure above or below the pistons in the cylinders) through the medium of a connecting rod, to which is attached a copper float. When the water level in the reservoir falls, the float follows it and the valve is opened, and the opening of the sluice gate follows. When the water in the reservoir rises, the gates are correspondingly closed. A four-

ton trolley hoist is provided for lifting the screens above the floor level to allow them to be cleaned.

Efficiency of Double Filtration.

The first place that I can recall where double filtration of water was used was at Schiedam in Holland.

As used in this city it has much to commend it.

1st. There is a general reduction in the unit cost of filtration.

Fig. 6.—Looking West on Central Court from Roof of Administration Building.

2d. The efficiency of the filters, that is, the length of run, between the cleanings is increased materially, and there follows that—

3d. The total output for a given size plant is considerably greater.

The following figures indicate what part of the work of purification is accomplished by each part of the process.

Prefilters operating at the rate of about 80 million gallons per day:

Average reduction of turbidity	70%
Average bacterial reduction	65%

Using the slow sand filter as a finishing process at an average rate of about five million gallons per acre per day:

Total reduction of turbidity 100%, *i.e.*, the turbidity is entirely removed.
Total reduction of bacteria averages 99½%.

Aspect of the Plant.

To one familiar with filter practice, this plant presents a different aspect from that of the London, Berlin and Hamburg plants in

Fig. 7.

Europe, and also the Albany and Washington plants, as well as the filters in our own city. In the first place, the wide and extensive court areas are missing. Originally, all of the sand, when it required cleaning, was ejected or otherwise removed to the courts, where the washers were located.

Washing the sand within the filters, as with the Nichols separator, or washing the sand *in situ* as with the Blaisdell washing machine (which was the original intention), or washing it by the so-called

Brooklyn method of raking and scoring the surface and washing it with a stream of flowing water, as first practised on the Hempstead filters of the city of Brooklyn, makes possible the reduction of court area, as little or practically no room for sand storage is required. The ratio of court area to total filtering area is 10.4 per cent. at Albany, and 25 per cent. at Torresdale in this city, while at Queen Lane the court area represents less than 3 per cent. of the total area of the combined filters.

Fig. 8.—Solid Dividing Wall in Filtered Water Basin in Rear; Orifice Casting in Roof Arch at Stop House.

Where washing as with the Blaisdell machine can be performed without draining off the water from the surface of the bed, and the mechanical raking up of the sand surface is rapidly performed, the time the individual filters are out of service for cleaning is reduced to a minimum. Consequently, in the design of a new plant contemplating mechanical washing of the sand *in situ*, fewer filters have to be provided for a given output; or, where the plant is already built and mechanical means are subsequently provided for washing the sand,

where that is practicable, without first draining the water off the surface, an increased output, beyond what the plant was originally intended for, is made possible. In the design of the original Philadelphia filter plants, allowance was made for having from 10.5 per cent. to 20 per cent. of the individual plants, with an average of 12.5 per cent. of the entire plant out of service at a time for the purpose of cleaning. At Queen Lane, the sand is washed within the bed, and the Sand Run entrance, quite a prominent feature of the ordinary

FIG. 9.—Dividing Wall in Filtered Water Basin in Background.

filter plant, is omitted entirely, and there is no necessity at all for the elevated sand storage tanks, as at Washington. The filtered water basin at this place is as heretofore mentioned, below the filters, and, hence, is entirely out of sight. At all of the other filter plants, the roof of the filtered water basin, when seen from above, is quite a prominent feature of the landscape, presenting a large, perfectly level plain, unbroken but for the inlet and outlet houses and for an occasional manhole. The Filtered Water Basin at the Torresdale Filter Plant in this city is of the same capacity as that at Queen Lane

and covers about $10\frac{1}{2}$ acres. There is no reason why the preliminary filters could not be placed on top of the slow sand filters ordinarily where the elevation of the ground is suitable, and thus make the plant still more compact. This, however, could not have been done at Queen Lane, where the bottom of the original reservoir was used as the floor of the filtered water basin.

Some time during the year 1901 the writer was engaged in developing and studying the Queen Lane Filter Plant at the site proposed by the Ashbridge Commission, and, as the land was quite expensive, and sufficient court room was not available (this was at the time when the sand was all removed to the courts for the purpose of washing it), he proposed to utilize the roof of the filters for the purpose of storing and washing the sand, which could readily have been done. The substitution of a properly reinforced concrete pier for the piers usually constructed of brick or mass concrete will still further reduce the space occupied by providing the same effective filtering area within a given (smaller) area. The total pier area, however, is not over two per cent. of the filtering area. Differences in the method of regulation and operation also exist at Queen Lane, but the further reduction in area required for a plant of a given capacity must come about rather as a result of an increase in rate of filtration by some preliminary treatment of the water, either chemical or mechanical, or a combination of these.

Construction of the Plant.

The Philadelphia, Germantown and Chestnut Hill branch of the Pennsylvania Railroad approximately parallels the plant at a distance of about 1200 feet, in a direct line from its easterly end. A railroad connection was built across the intervening property on a private right of way for the purpose of transporting direct to the site of the work all of the materials used in its construction. A car storage yard with ample trackage was built in connection with the siding, to provide for storage on the tracks of the materials required from day to day. A piece of property containing upward of four and a half acres was also provided for lumber and pipe storage, adjacent to the siding. In this yard is located the general store-house and blacksmith shop for the plant, as well as a saw-mill and carpenter shop, where the concrete forms for use on the work were built. In this yard were also stored the reinforcing rods, upward of 5,000,000 pounds of which were required to be built into the work.

The junction with the main line was made at a point distant about 2,000 feet from the nearest part of the work. Considerable difference of elevation between the tracks of the main line and the objective point required the use of heavy grades. Where the siding joins the main line, the road bed was widened and two additional tracks, each 600 feet long, were laid parallel to the main line. A timber trestle about 25 feet high and about 250 feet long, on a 10 degree curve, was built between the railroad embankment and the high ground immedi-

Fig. 10.—Interior View of Slow Sand Filter, Sand Removed.

ately to the westward. From this point, the road was built in cut and fill on private right-of-way, the maximum grade approximately 4 per cent. to Fox Street. From this point, the tracks are laid on the street surface.

To provide storage for sand and stone adjacent to the concrete plant, a spur was taken off the main track where it emerges from the private right-of-way and built on an embankment, on a grade of 3.5 per cent. to a point in front of the concrete-mixing plant, where bins were excavated in the bed of the street and a trestle built over

them so as to be filled from the cars. The stone bins had a capacity of 20 cars and the sand bin a capacity of 12 cars. 100 lb. rail is used in the sidings and yards throughout. Spur tracks or sidings are also laid so as to reach the general storehouse, the lumber and pipe yards, etc.

For the hauling and handling of all freight and materials on the work there was provided a 75-ton steam locomotive and also a 45-ton steam switching engine, as well as a 15-ton locomotive crane.

Demolishing the Reservoir Banks.

The work of cutting down the north, east and west embankments of the original reservoir was done with a 30-ton Vulcan (Little Giant) Steam Shovel, having a 1 cubic yard dipper and loading into drop bottom wagons. The earth was hauled from under the shovel to the site of the various fills, where it was sprinkled with an ordinary sprinkling cart and rolled with a 10-ton steam road roller, manufactured by the American Steam Road Roller Company.

The slope lining of the reservoir consisted of concrete, varying from 6 inches at the top to 12 inches at the foot, on which had been laid a layer of brick, flatwise, as in an ordinary pavement, in herring-bone bond. The cementing material was of hot asphalt.

The concrete lining was painted with liquid asphalt, a layer of burlap was laid, and another paint coat of asphalt applied. The bricks were removed from the slope in every case prior to the cutting down of the banks with the steam shovel.

When the water was drained from the reservoir, and after drying, there was found to be about four inches of sediment on the floor, which had accumulated since the reservoir was first built, say in about sixteen years. To remove this, several methods were tried, but the most effective seemed to be that of shoveling it into piles and loading into dump wagons with ordinary scoop shovels. It was attempted to use drag scrapers, and, at another time, an ordinary road machine for the purpose of scraping the sediment into piles, but, as the dirt layer was quite thin, these methods were not found to work well.

Original Stop House.

The original stop house, which had to be taken down, was located in, approximately, the center of the east bank, and consisted of massive rubble masonry which could be removed only by blasting.

The powder used was 40 per cent. dynamite, and the drilling was done with ordinary steam-driven, tripod mounted, rock drills. The only rock on the work which had to be blasted was in the sewer trench on the line of Bowman Street. The concrete on the slopes was broken up with the steam shovel, was mud capped, and, in many instances, sledged, so as to reduce it to the proper size for placing in the fill.

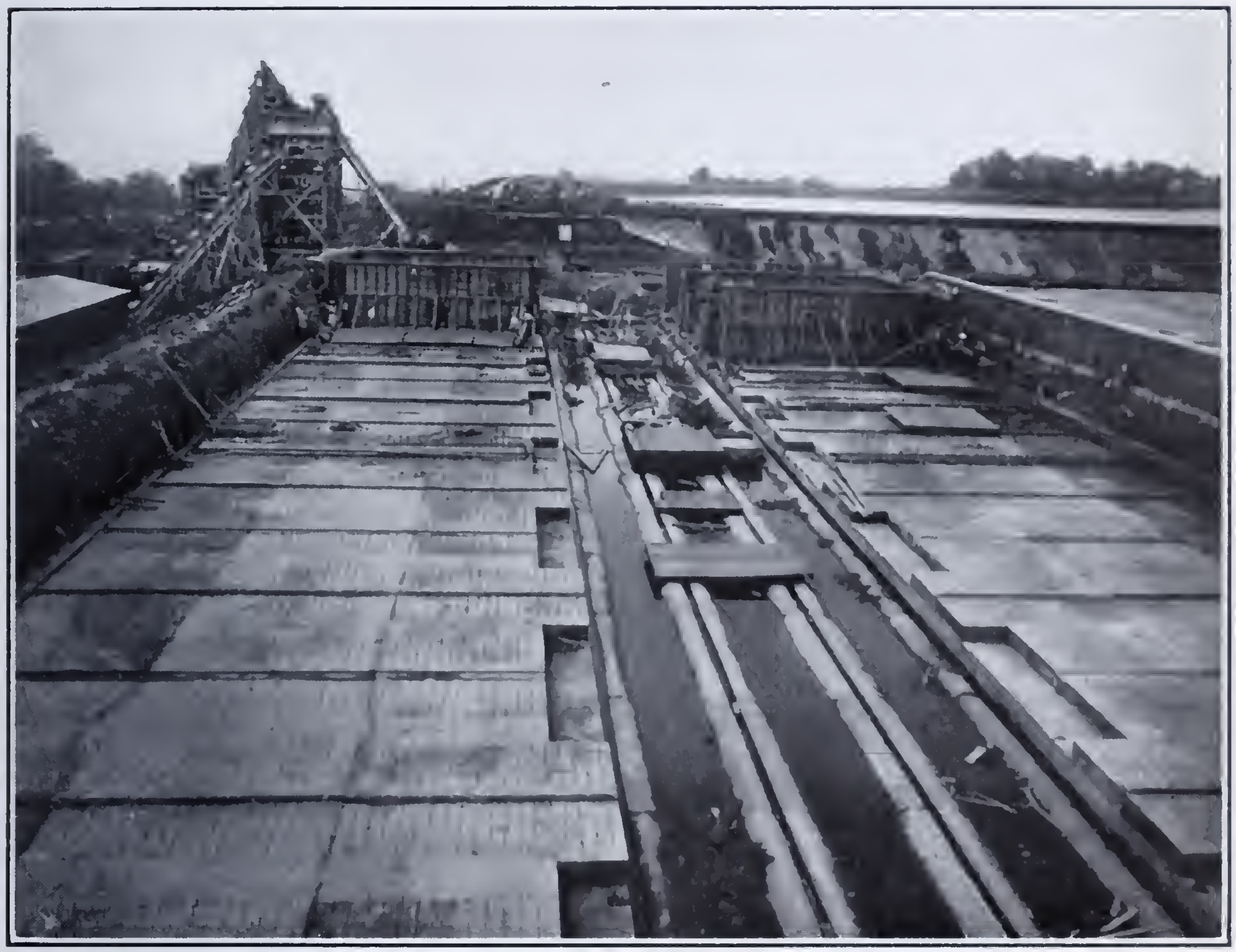


Fig. 11.—Prefilter Floor.

Cutting Through the Floor of the Basin.

The floor of the reservoir consisted of four inches of stone concrete and two inches of a bituminous concrete, which latter material was placed subsequent to the building of the original basin in the process of making it watertight. The design of the new work necessitated the cutting of nearly 3,000 holes, each approximately four feet by four feet through the floor of the original reservoir, and also trenches following the north, east, west and division banks, as well as one through the center of the basin from east to west for the purpose of

building the footings for the piers and the main walls on which the new work was constructed. All of the pier holes and trenches were carried down to rock bottom and the new structure is built entirely on solid rock.

Geology.

The surface of the rock is, generally, about four feet below the level of the original bottom of the reservoir, and is almost uniformly level over the entire site, excepting in the extreme westerly corner of the

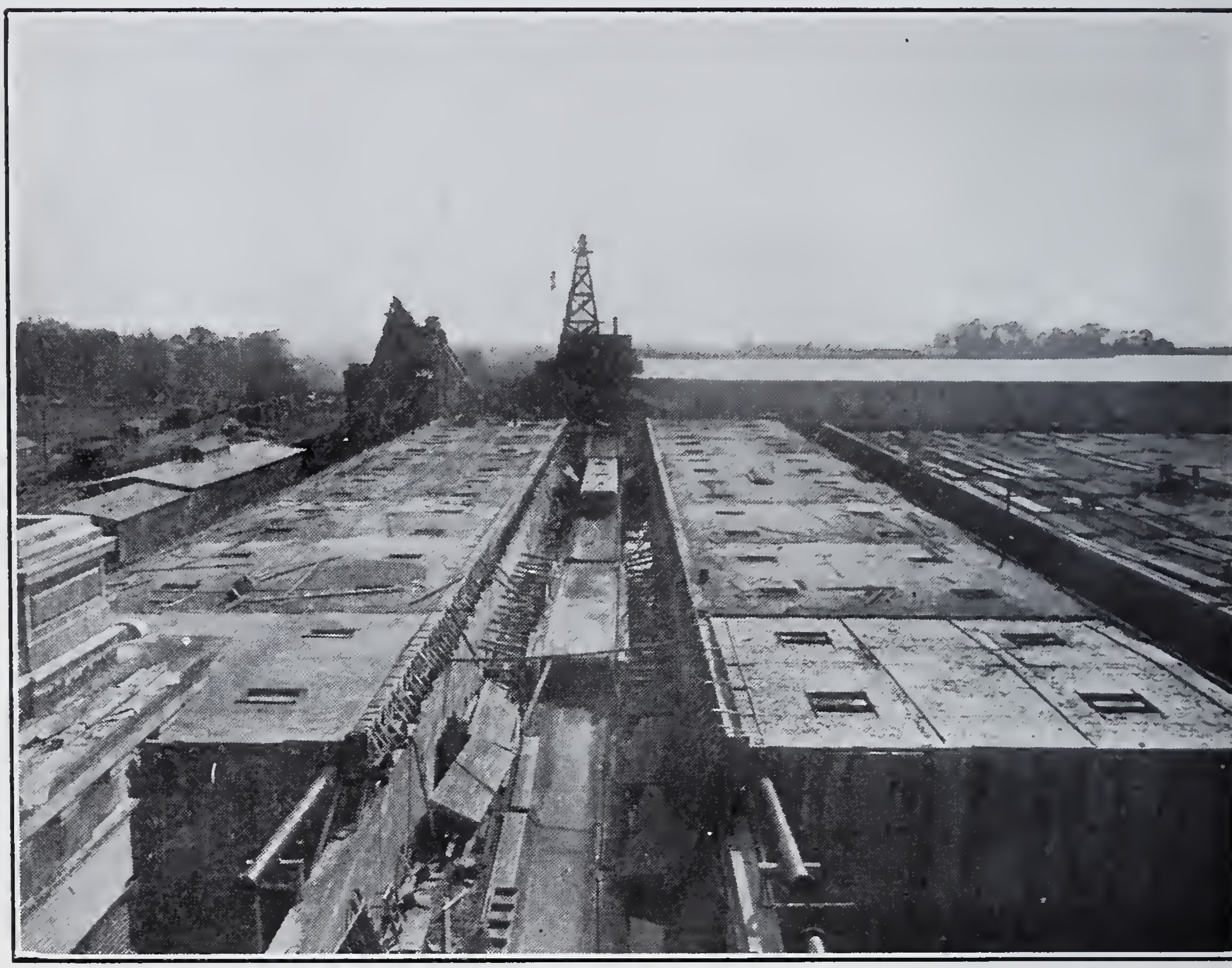


Fig. 12.—Looking South Over Prefilters from Top of Tank Tower.

reservoir, where it dips abruptly and is about 20 feet below floor level at this point. The rock is the typical Philadelphia mica schist, which outcrops in many places in the adjacent country.

Filter Construction.

The piers, which are 30 inches square and placed 16 feet center to center, used for supporting the groined arches, are founded on the footings at the level of the underside of the floor of the filtered water

basin, and are carried uniformly about two inches above the level of the springing line of the groined arches. The curved side walls on the north, west and south sides and the retaining wall on the east side of the basin, as well as the wall which subdivides the basin, are all founded at the level of the underside of the basin floor. The groined arches are similar to those used on all of the other filter plants in this city and elsewhere, excepting as to dimension and to the fact that they are reinforced with steel, and that in this case the concrete of which they are built is carried level from the crown at the extrados, where it is 10 inches thick over the piers, making a perfectly level floor covering the entire area, as this constitutes the floor of the final filters as well as the roof of the filtered water basin. On this floor are built the walls subdividing the area into 22 separate filters and also the partition walls subdividing each unit filter into three compartments.

The roof of the final filters consists of slab and girder construction of reinforced concrete, supported on columns or piers built on top of the dividing walls. The span of the main girders is uniformly 32 feet, and the reinforcement consists of plain, round rods. The main roof slab, to allow for expansion and contraction, is divided into blocks, the majority of which are 32 feet by $53\frac{1}{3}$ feet, a joint about $\frac{1}{2}$ inch wide separating the blocks. The roof blocks were placed alternately, wooden bulkheads being used to define the limits of each block and to act as a form for the concrete. The interior or alternate blocks were placed after the first set of blocks were poured and after the concrete had set. Against the hardened concrete was placed a steel diaphragm consisting of three No. 10 sheet steel plates, heavily coated with grease, each in sections of about 5 feet 4 inches long by about 28 inches deep, to conform to the arched shape below where necessary, the center ones being $2\frac{1}{2}$ inches deeper than the others, so as to allow of their withdrawal from above without disturbing the outside plates. After the concrete had set and when these plates were removed, an open joint about $\frac{1}{2}$ inch in width separated the blocks.

On the rolled embankment at the easterly end of the plant was placed a layer of clay puddle under and around the walls of the preliminary filters to the height of the flow line. The material consisted of clay and broken stone in about equal proportions, mixed together in a Chambers No. 7, extra heavy, geared pug mill. The mill had a tub 10 feet long and the pug shaft was of steel, four

inches square, was operated at about 45 revolutions per minute, and has a capacity of 60 to 75 yards per day. The machine was belt-driven, a 25 H.P. General Electric series wound, 500 volt direct current motor furnished the motive power. The puddle was placed on the floor in two layers and rolled with a 10-ton steam roller. Where it was placed vertically, as around the walls, it was tamped with iron rammers weighing 20 pounds each. The pug mill was erected on an elevated platform so that the wagons could be backed in under the discharge end of the machine.

FIG. 13.—Prefilters Showing Power House in Distance.

CONCRETE PLANT.

The concrete handling plant consists of a Haines gravity mixer with the elevating apparatus for the sand, stone and cement, a cement storage house of 20 cars capacity, a complete third rail electric tramway, double track outfit for delivering the mixed material to two Lidgerwood traveling cableways, operating in a direction at right angles to the electric road. Two types of buckets were used

in connection with the cableways—the Haines bucket, in which the contents is discharged through a rather contracted circular opening in the bottom, and the Doud's Acme bucket, which, by means of a system of levers, the entire bottom of the bucket, consisting of two separate leaves, is entirely drawn aside, exposing an opening the full cross-section of the bucket.

The concrete is mixed in the Haines machine, is drawn off from the lower hopper into one or other of the buckets, is run out over the

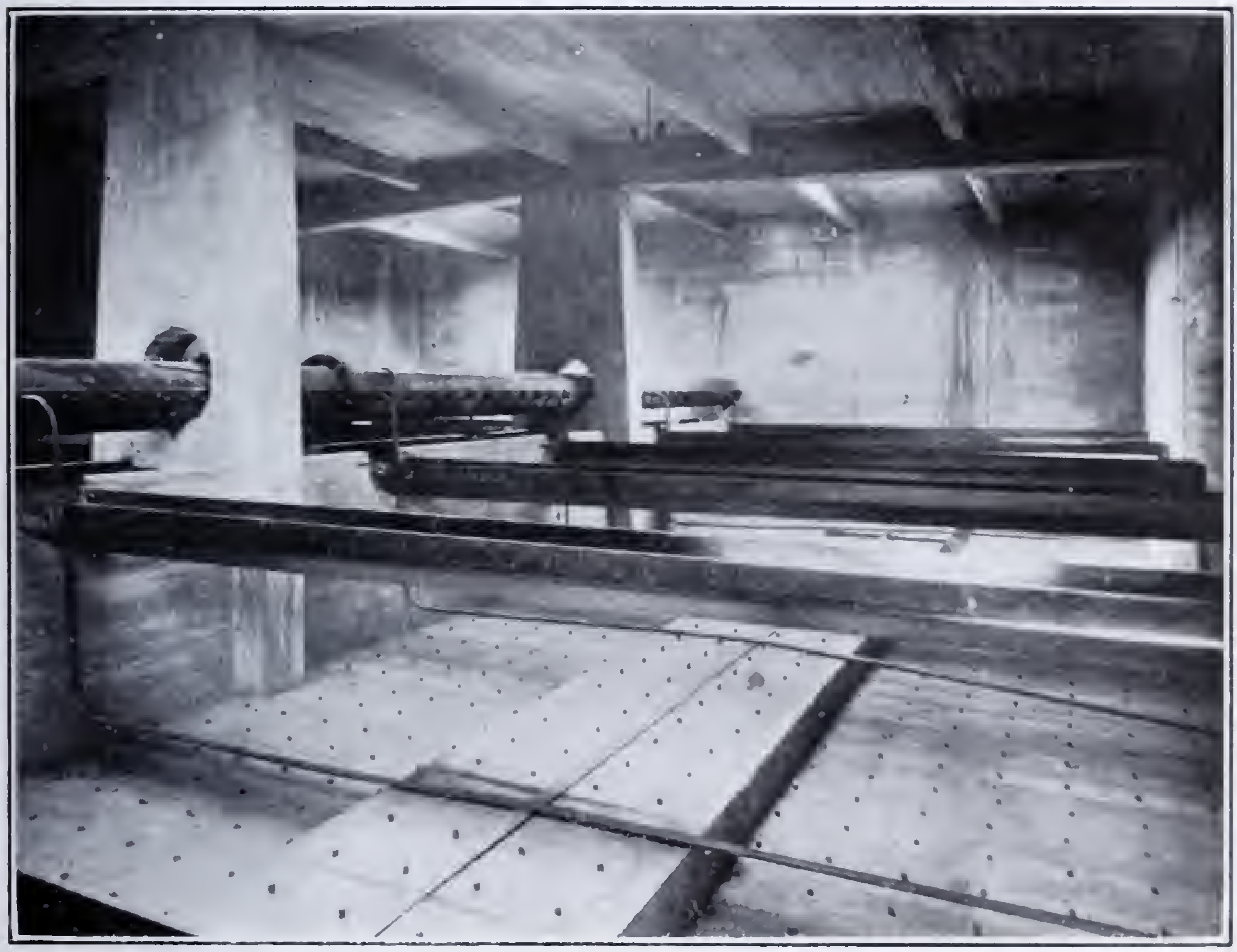


Fig. 14.—Prefilter Floor.

electric road to a point opposite which it is proposed to deposit it, and is picked up off the car by either of the two cableways and thereby transported direct to the forms where it is intended to place it.

The mixing plant is situated at the southeasterly corner of the work. It is mounted in an elevated timber framework erected on the outside slope of the reservoir. It is surmounted by a bin of a capacity of 50 tons of sand and stone, from which the material is fed to the mixing hoppers through sliding gates in the bottom of the bin, the gates being immediately over the four mixing hoppers located on the

floor at this level. The stone and sand are elevated to the bins by bucket elevators, the total distance from the bottom of the storage bins at the foot of the mixer tower to the head shaft of the elevators being 75 feet. The material is first elevated to the level of the operating floor in an elevator outside the front face of the conveyor tower, the shafting, etc., being supported above the level of the operating platform on a timber framework, cantilevering out at the floor level over the stone and sand storage bins at the foot of the

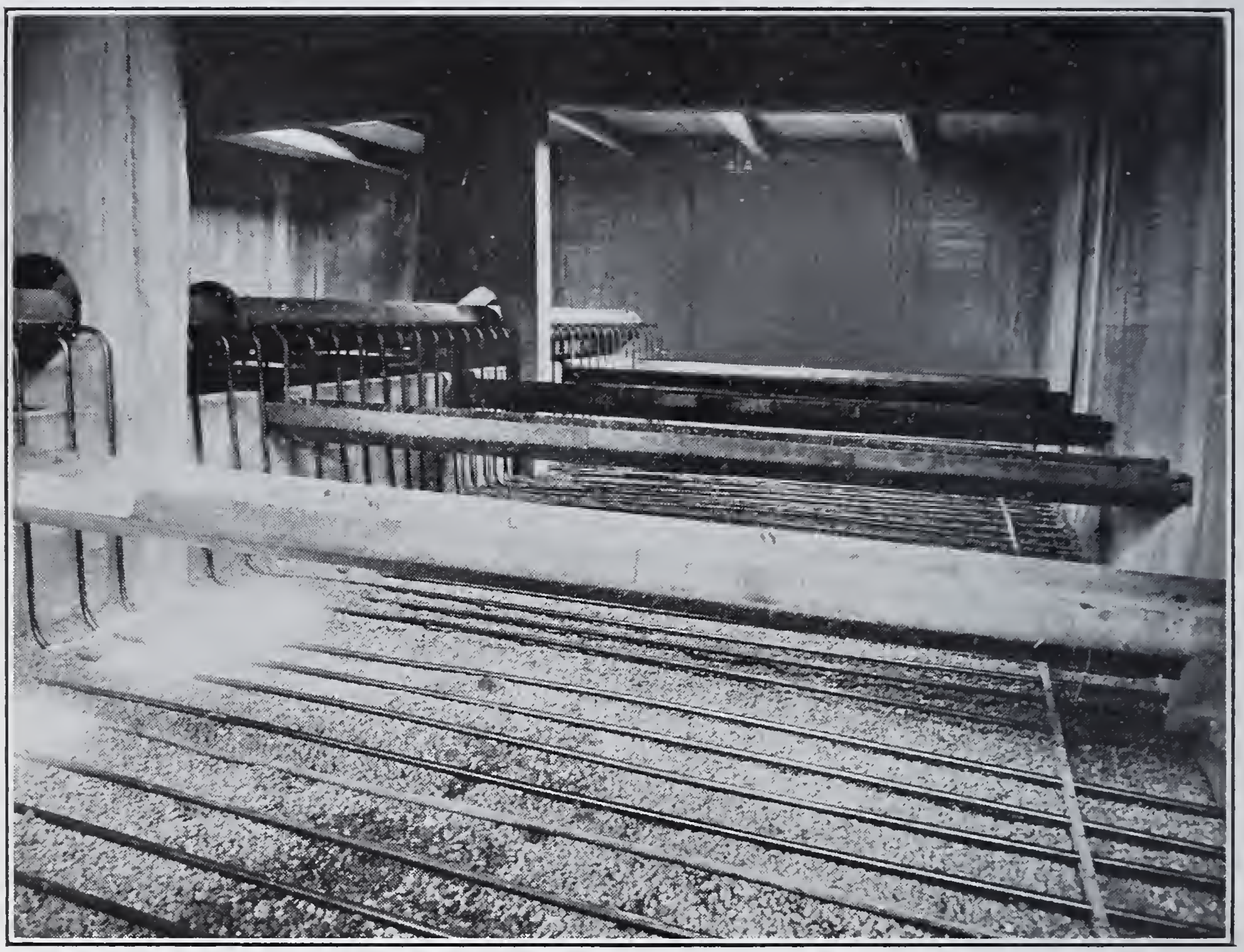


FIG. 15.—Interior of Prefilter, Showing Wash Water Troughs, Air Manifolds, and Filtering Material (Lower Layer).

tower. At this level are placed the chutes, into which the lower elevators discharge into the steel boots of the upper elevators, thus changing the direction of the elevators at right angles, and finally bringing the material to the level of the bins surmounting the mixing tower. It is thus seen that two separate elevators are used for stone and two for sand, the combined lift of each pair of elevators being 75 feet. The sand and stone elevators are driven from the same shaft by a 50 H.P. General Electric D. C. motor, located in an

enclosure on the operating floor at the level of the head of the lower elevators.

The elevators for the sand, owing to the abrasive action of that material on metal, were made of seven-ply rubber belting, 20 inches in width, with steel buckets spaced 24 inches c. to c. The elevators for the stone were made of No. 844 "Ley" steel-bushed chain, working over chilled rim sprockets 24 inches in diameter. As both elevaters were run from one shaft and as twice as much stone was required as sand, the buckets on the stone elevators were spaced 12 inch c. to c. The buckets were of No. 10 sheet steel 14 inches long by seven inches projection by $11\frac{5}{8}$ inches deep. The elevators were run at a speed of 240 feet per minute, and the capacity of the stone hoist was 600 cu. yds. and the sand hoist about 300 cu. yds. per 10 hours. At the above speed, the apparatus was good for 40 per cent. overload. The elevators were fed at the foot through chutes which were built above the steel boots in which was supported the shafting carrying the sprockets at the lower end of the elevators. The bearings for the foot shafts were attached to the take-ups for adjusting the slack in the chains.

The cement hoist consisted of an inclined runway on which a chain belt, to which were attached a number of wooden flights, served to elevate the cement in sacks from the ground level to the level of the mixing floor on the concrete mixer. The flights, to each of which were attached two small flanged wheels, were fastened to the chain with special connections and ran on a flat iron track on the wooden side rails of the runway. There were 22 flights, each of which consisted of two sections, and the rear section in each case carried two cast-iron brackets for supporting the sacks. The chain used was No. 95 pintle riveted link chain with sprockets 18 inches in diameter. The drive distance was about 65 feet, and the vertical height or lift was in the neighborhood of 50 feet. The elevator was driven from the head end by a $4\frac{1}{2}$ H.P. Crocker-Wheeler D. C. motor, situated on the mixing platform. The speed of transmission was about 50 feet per minute, and the capacity of the machine at this speed about 3,000 bags per ten hours.

Adjacent to the foot of the cement elevator was located a cement storage house of a floor area inside of 30 feet by 80 feet, divided into 20 separate bins arranged on both sides of a central aisle, each bin of 8 feet by 12 feet area, which provided for the easy storage of 20 carloads of cement when piled about 5 feet in height. All of the

cement used in the work was inspected at the mill (and again on delivery at the plant), and was generally unloaded direct from the cars in which it was shipped to the cement elevator. It was, however, deemed prudent to have on hand at all times a stock of at least 20 cars, to provide against unavoidable delays in transportation.

The mixer could be fed from city water pressure through a 2-inch wrought-iron water-pipe connecting with the service pipe in Fox Street; or, when there was not sufficient pressure, the supply was had

Fig. 16.—Interior View, Prefilter Gallery.

from a tank of 500 gallons capacity, supported above the stone and sand bins at the top of the mixer tower. The tank was filled from the south basin of the Queen Lane Reservoir. On a platform built above the normal water level in the reservoir was located a Franklin two-stage turbine pump direct connected to a Westinghouse motor. The pump was started from the motor room on the mixer tower. A 3-inch pipe was taken off at the bottom of the tank and subdivided into four 1½-inch branches, on each one of which was a globe valve to cut out the supply if required. A quick acting valve controlled

the flow from the tank, and was ordinarily used to supply the water used in mixing the batch. The water in the tank was kept at a constant level, and the quantity of water fed to each batch was gaged by timing the opening and closing of the quick acting valve.

Double Track Electric Road.

A double track electric road of 36-inch gage with three crossovers was laid from a point immediately under the mixer the full width of the work, a distance of about 1,200 feet. From a point about 100 feet from the mixer the road was laid on a wooden trestle built on the north slope of the division embankment on a grade approximating 1 per cent. away from the mixer. Invariably, after starting the car by power and running for 150 feet or so, the car had sufficient momentum to coast to any point on the line. Power was always required to bring the cars back under the mixer. One hundred trestle bents all exactly alike were built and set up on the reservoir slope at about 12 feet centers, the lower sill butting against the edge of the brick lining, a sufficient number of bricks having been removed to bed them. The rails were laid without ties on 8 inch by 10 inch stringers, one under each rail, which were bolted together.

Thirty-pound T-rail with plate frogs and spring switches was used. The rails were bonded at the joints with (two—$\frac{5}{8}$ x 24 inches) twisted copper bonds. The third rail was a No. 12 T-rail supported on porcelain insulators at 12 feet centers and properly bonded with copper.

Rolling Stock.

The rolling stock consisted of five motor cars and five trailers coupled together in pairs. The motor cars were built with a steel underframe and with a wood floor laid doubled. The free floor space is practically 5 feet by 4 feet 6 inches. The car weighs approximately three tons light. Each motor car is equipped with a 15 H.P. Westinghouse series wound D. C. motor and with the necessary resistance and control, hand brakes, etc. The trailers were ordinary, well-balanced steel frame flat cars with wooden floors 4 feet by 5 feet.

Cableways.

Two Lidgerwood traveling cableways of 909 feet span were used to distribute the concrete from the cars to the forms. These cableways spanned the work in a direction from north to south, the towers

being provided with running tracks on the north and division embankments of the old reservoir. The north bank was first cut down approximately to the finished grade, while the division embankment, on which the head towers were placed, had to be maintained at the original grade. The north bank, after being cut down to base level, was sufficiently broad for the placing of the five lines of rails which were required. The division embankment was, however, only 25 feet wide, while the base width of the head tower, including the over-

Fig. 17.—Operating Table, Prefilters.

hang of the ballast boxes, was about 41 feet. The distance center to center of outside rails, on which the car supporting the head tower ran, was actually 32 feet. These were unusual conditions in the operation of a cableway, namely, that the tail tower should operate on a track materially below the level of the track of the head towers and that the track of the head towers should be supported partly on solid embankment and partly on a timber trestle overhanging the bank. After considerable study it was decided to overhang the back of the bank over the water in the south basin of the reservoir. Accordingly,

wooden sills were laid on the south slope of the division bank, after first removing sufficient of the brick lining so that they could be bedded on the concrete and bear against the brick on end at the bottom of the sill. In line with these sills, which were placed 10 feet center to center, and extending over them, were placed timbers about 36 feet long, blocked up on the division bank. These sills were fastened together at their intersection with two cover splices. Two lines of vertical posts were built up on the sills laid on the slope of the basin, and substantially tied together with diagonal bracing and capped with timbers across the whole length of the trestle, which was about 1200 feet. The timbers were all drift bolted at their intersections.

On the trestle thus constructed were laid the running tracks for the operation of the head towers. The rails were laid two under the front end and three under the rear end of the towers, immediately under the operating machinery. The rails weighed 70 lb. per yard, and were laid on ordinary ties to standard gage (4 feet 8½ inches) about 24 inch centers. These ties were cribbed up to the level of the top of the transverse trestle timbers and the rails were spiked to the timbers at every crossing point as well as to the ties. This formed a very satisfactory roadway for the head towers.

The track for the tail towers was laid on the subgrade of the north bank as excavated on ties spaced about 13 per rail length and ballasted with cinders. There was a tendency due to a tension of about 34 tons in the main cable (with a deflection of 5 per cent. of the span and the normal load) to bring the tracks of the head and tail towers together. After the tracks had gotten their bearings, however, little trouble was experienced from this source.

The working capacity of the cableways was 4½ tons, and they were intended to be operated at a speed of from 1500 to 1800 feet per minute. In practice, however, 1200 feet per minute was the usual speed at which they were operated, and was rarely exceeded. The towers and the cars supporting them were framed of squared timber securely bolted together at the joints and tied together with through rods adjustable by turnbuckles. Each car and tower had approximately 25,000 feet BM. in it and weighed, complete with all the operating machinery, ballast, etc., upward of 125 tons. The height of the head towers was 64 feet, and of the tail towers 74 feet, above the head of the running rails.

The main engine was a double cylinder 10 inches by 12 inches

double friction, reversible link motion, Locke's patent cableway engine with transmission and conveying drums 53 inches in diameter. The auxiliary engine for moving the towers was a double cylinder, double drum 7 inches by 10 inches engine, and the boiler was a Stroudsburg vertical tubular boiler of about 60 commercial H.P. The water supply for the boilers was usually taken off a 1½ inch WI. line connected with the city pressure. For the purpose of an auxiliary supply each of the head towers was provided with a Snow or Worthington 6 inches by 4 inches by 6 inches duplex pump for pumping direct from the reservoir into a 600 gallon tank carried on the tower platform. The towers were usually moved at a speed approximating 150 feet per minute by pulling on a line of ¾ inch cable operating through a 12 inch sheave and thence to the drum of the engine, attached to a deadman at each end of the run. The tail tower could be moved by the head tower by simply dragging it along by the main cable as has been done in many instances, but it was deemed wise to provide each of the tail towers with a moving engine of its own. For this purpose, a 7 inch by 10 inch double cylinder, double drum, hoisting engine and vertical boiler were used. The cableways were provided with an electrical signal system, reaching all parts of the work, and the towers signalled each other, using an accepted code with steam whistles placed there for that purpose. The main cable was 2 inches in diameter, of extra strong crucible cast-steel cable. The fall rope when run out was carried in the usual manner of the Lidgerwood cableway by fall rope carriers, operating on a button line of an improved design. The carriage was similar to the carriage of the cableways built for and in use on the Panama Canal, and the horn for picking up the fall rope carriers was of the same style as that used on those machines. Each head tower was provided with 12 pairs of cast-iron car-wheels, and each tail tower car with 14 pairs of wheels, 24 inches in diameter, with 4 inch axles.

Auxiliary Concrete Plant.

Certain isolated portions of the work which were not covered by the cableways were put in with the auxiliary plant provided for the purpose. This consisted of two No. 2½ Smith mixers of $\frac{2}{3}$ cu. yd. capacity, each operated by 10 H.P. C and C direct current motors. The mixers were loaded with an elevating apparatus driven from the main drive shaft of the mixer. A No. 0 Smith concrete mixer on wagon wheels was also used on this work. The capacity of this

machine was about $\frac{1}{3}$ cu. yd. The machine was driven by a 6 H.P. Fairbanks-Morse gasoline engine.

Accident to Head Tower.

On May 25th, 1910, at 6.30 P. M., in a tornado which occurred during a rainstorm, the head tower of No. 1 cableway blew off the bank, falling a distance as measured vertically of 40 feet, more or less, and became wedged in between the stone wall at the foot of the

Fig. 18.—Accident to Head Tower.

bank and the ballast bin below the concrete mixer. The main cable caught over the headstock of the concrete mixer and several of the car and tower timbers were broken in the fall. The frame of the main engine was broken in three places and the forged steel axles of five of the sets of running wheels were bent so that they had to be straightened.

The tower, in its fall, swung around more than 90 degrees, and the rails were seemingly not distorted, which appears to indicate that

the tower, which weighed upward of 125 tons, was lifted bodily from the rails, and that all of the wheels of the car had practically left the rails before it changed its position, due to the direction of the main cable and the location of the machinery. By one who observed the fall of the tower from a distance, it is said to have made at least three ineffectual attempts, so at speak, to leave the rails. The tower was anchored for the night at least 150 feet from the edge of the bank where it went over. It is said that it was driven three times up against some railroad ties which were laid as a barrier across the tracks to prevent such an accident occurring. The tracks for the head towers were laid level over the entire length, excepting at this end of the bank, where it was thought that some accident or other might occur to the moving engine, which would render it unmanageable. As a precaution, the tracks were laid on an up grade of ½ per cent. for a distance of about 150 feet, to act as a brake. In its forward, as well as its retrograde, movement, due to the action of the wind, the cables set up a swinging motion, drawing the tail tower along in the wake of the head tower, and this, no doubt, materially assisted in furnishing the momentum to the head tower. The tower itself being a framed timber structure presented very little surface to the wind. The engine house which was built on the floor of the car, and the ballast boxes, however, presented considerable area. The entire tower had to be taken apart and rebuilt, and the carriage and all of the cables were taken down and restrung, the engine and boiler repaired, the axles straightened, and the tower was again in operation on June 17, 1910, involving a loss of twenty-two days' actual working time. The work could have been completed in eighteen days, had it not been necessary to send the wheels and axles away from the plant to be straightened.

Plant for Handling Filtering Material.

The material was dumped from the railroad cars into one of two bins of a capacity of about 25 cu. yds., each excavated below the ground level under the railroad tracks. These bins were lined with timber and sheet iron, and were controlled by iron shifting gates, operated by hand levers from below. All-steel, side dump cars of 1½ cu. yd. capacity were lowered down on an inclined plane from the level of the main roof below the bins, and filled by releasing the levers. The loaded cars were then hauled to the roof level, two at a time, by a cable haulage system, operated by a 7 inch by 10 inch double-cylin-

der double-drum steam hoisting engine. Cars were coupled together in trains of about 12 on the roof, and were hauled to their destination by a 6½ inch by 12 inch steam tank locomotive, weighing 6½ tons. The main track which was laid on the filter roof, and which followed the central court at a uniform distance of 26 feet from the north court wall the entire width of the work, had two parallel legs or connections with a crossover between them at right angles to the main line, to the edge of the roof, and connected at that point with the inclined plane to the

Fig. 19.—Locomotive and Cars for Transporting Filtering Materials on Roof of Filter.

loading bins. The main track was built in portable sections of 20 lb. T rail, 24 inches gage, laid on two 10 inch by 14 inch by 32 feet stringers, one under each rail, blocked up over the filter walls, so as to put no undue load on the roof slab. The spur tracks were all of 16 lb. T rail made up in sections of portable track, and were laid on two 6 inch by 8 inch stringers, one under each rail, on bents spaced 5⅓ feet apart, of varying height. These latter tracks were all operated by gravity. The cars were hauled on the main track

by the steam locomotive to a particular filter and thence shunted to the gravity spur tracks (through a system of portable curves and switches), laid alongside the skylights or ventilators in the filter roof. The cars were then dumped into a hopper and chute, so that the material landed direct on the filter floor through the ventilators. About 24 cars were provided. The filtering material was spread by hand. About 7 per cent. in excess of the actual depth required was placed to allow for settlement after the application of the water.

Evolution of the Process of Slow Sand Filtration.

It is curious, and at the same time interesting, to note the changes of opinion on the subject of water filtration. It is an evolution in fact as well as in name. Water filters of some type or other have been used for at least two thousand years. In the volume describing the aqueducts of ancient Rome, of Parker's "Archæology of Rome," is depicted the construction of the Piscinæ or filters which were built in the line of the aqueducts. Sextus Julius Frontinus, Water Commissioner of the City of Rome at the beginning of the Christian Era, in his "Two Books on the Water Supply of the City of Rome," the English translation of which is due to Mr. Clemens Herschell, states that the object of these Piscinæ "was to catch the small pebbles as they come down the aqueducts and thus prevent them from getting into and stopping up the lead pipes," etc. This, of course, would hardly be considered as more than a rough straining process, intended to rid the water of its grosser particles, but this idea of filtration is no more obscure nor clouded than many of much more recent date.

In the Report of the Watering Committee of City Councils of 1854, which is accompanied by a report of Frederic Graff, Esq., Superintendent of the Fairmount Water Works, on "Filtration," Mr. Graff, then eminent in the profession, makes the statement that "It is well known that filtration only purifies the water by arresting the solid organic matter, while it does not remove the fluid organic matter, the salts, gases and other soluble impurities." As late as January, 1890, so eminent an authority as Dr. Thomas M. Drown, who was among the very first to establish the science of filtration, and whose labors at the all-important Lawrence Experiment Station on Water and Sewage Purification are recorded in the memorable "Report of the State Board of Health of Massachusetts for 1890," in a lecture before the Boston Society of Civil Engineers, says, "In the study of the subject of filtration of water for drinking purposes we

shall arrive at no clear and valuable ideas unless we distinguish, sharply, between mechanical filtration, which deals only with the interception and retention in the filter of the solid particles suspended in the water, and filtration, combined with the oxidation of organic matter, that in solution as well as that in suspension in the water. The latter process, the purification of water by the oxidation of its organic contents, can be accomplished only by Intermittent Filtration, the former, the mere removal of the solid particles in the water,

Fig. 20.—Raw Water Intake.

may be accomplished by continuous filtration, as practised in many large cities in Europe."

It will be remembered that at the Lawrence Experiment Station, of which Dr. Drown was the first executive head, great stress was laid on the idea of the intermittent or non-continuous use of the filter bed. It was thought that as the plant life on which the biologic action of filtration depends requires air in its vital functions, it was necessary to apply the liquid intermittently, so that during the interim between the successive dosings the air could have access to

the sand beds. The fact that the applied water itself carried free air in solution, sufficient for the vital functions of the bacteria, was rather overshadowed by the fact that the sewages, which were experimented on in the station at the same time, carried no free air, and consequently required that the beds be used in an intermittent way.

The theory of slow sand filtration at best is but very imperfectly understood. When the early filter works of London, England, were built, and when, later, Kirkwood proposed a system of filters for St. Louis, Mo., on what he called the English system, the straining power of the sand alone was supposedly the vital point in the process. For years the Germans held that sand filtration was purely a straining process, dependent on the formation of a layer or film on top of the sand, which they called the "Schmutzdecke," which word has been carried over into English technical literature to designate the zoöglea or jelly-like mass which forms on top of the sand bed after it has been in operation for some time. A literal translation of this word has an important bearing on the subject, and would seem to indicate that they considered it was the sediment layer, without regard to its organic nature, which was the important factor, although the biologic action of the film seems to have been early recognized by Koch, and the retention of the word serves as an indication of the direction through which the scientific work affecting this process has come to us.

It was in 1885 that Percy Frankland in England first demonstrated the difference in bacterial content between an unfiltered or what is commonly called a raw water and a water which has passed through a slow sand filter.

In 1893 Koch of Berlin brought out his monograph on Water Filtration and Cholera, and this paper no doubt produced a tremendous influence and probably the biggest impetus that the subject of water filtration was ever given. He showed how the careful filtration of the water supplied to Altona from the Elbe saved that town from the epidemic of cholera which came upon Hamburg as a result of drinking unfiltered water, although Altona is situated several miles below Hamburg and its drinking water is taken from the river Elbe after it has received the sewage of Hamburg.

The classic investigation conducted by the Massachusetts State Board of Health, particularly that referring to the oxidation of organic matter in water through bacterial action, was the most

important step in the study of the process to that time; and all of the subsequent work at that laboratory, supplemented as it was by similar work at numerous other laboratories throughout the country, fashioned on the lines laid down by them, has resulted in the demonstration of a principle that the foregoing factors, and probably many others more or less complex, now only imperfectly known or understood, or probably not now known at all, play important rôles in the filtration of water.

Conclusion.

Notwithstanding what has been said of the merits of slow sand filtration as applied to water, the writer is convinced that this process has passed its zenith, and if we have not witnessed the construction of the very last municipal slow sand filtration plant, we have certainly seen the completion of one of the last plants of this type to be constructed in America. The slow sand process is elaborate and costly of installation and operation, and requires quite a large land area, not always available, for any considerable plant. The system under competent supervision is so perfect from a sanitary point of view as to leave little to be desired, but on account of its very perfection its construction is believed to be economically in error or at least open to question.

To quote the late Ashbel Welsh, "That is the best engineering, not which makes the most splendid or even the most perfect work, but that which makes a work that answers the purpose well, at least cost." The two qualities of drinking water that appeal more to the lay mind than any other are taste and appearance. The slow sand filtration process does not usually affect the taste, particularly if it is of organic origin, and it is often deficient in removing turbidity, particularly in the early spring, when our rivers are in flood and generally more than usually turbid. The writer is further convinced that the future water filtration process will partake of the nature of the mechanical filter, probably on the lines of the preliminary filters described in this paper. The process may be preceded by sedimentation, precipitation with aluminum sulphate, and also sterilization with the ultra-violet rays. The last process is still untried on the large scale. Most probably hypochlorites will be used. This method has recently come into vogue and is very effective and economical and marks a considerable advance as well as a distinct era in the art of water purification. Incidentally, it may be said that while such a process is quite

elaborate and requires supervision of a very high character, the cost of construction will be far less than that of a slow sand plant of equal capacity, for ordinary river water. The saving in the cost of the land alone required for the installation of a plant of considerable capacity, of the future type, over the slow sand system, would go a great way toward paying for the construction of the plant of the type proposed.

DISCUSSION.

Mr. Vogleson.—The completion of the Queen Lane Filtration Station marks the final step in the work of introducing filtered water into the distribution system of Philadelphia, and it is perhaps fitting to briefly review at this time the steps in that work and to state some of the results therefrom.

Construction work for the improvement and filtration of the water supply was begun in 1901 at the Lower Roxborough Station, and upon the introduction of filtered water from this station into the twenty-first ward the cases of typhoid fever in that ward were promptly reduced. Further benefits from the improved water supply were had when it became possible to supply the twenty-second ward and some adjacent territory, upon the completion of the Upper Roxborough Station in 1903. The next step was made when, in 1904, the Belmont Station began to furnish filtered water to part of West Philadelphia. These three stations filtered at that time about one-fifth of the water supply from the city pumping stations, and although the benefits of filtered water were early shown by the reduction in typhoid fever in those districts which could then be supplied from the filters, the city was still scourged with typhoid fever, having in 1906 a mortality rate of 72.4 per 100,000, which had been exceeded only once in the preceding decade, when the rate reached 74.9 deaths per 100,000 in 1899.

In 1907 the Torresdale Station was placed on one-half capacity, and in 1909, upon the completion of the preliminary filters, was increased to its full capacity, marking the last step but one in completing the filtration of the water supplied by the city. The final step, as has been already stated, was the completion of the Queen Lane Station. The results of this work in relation to typhoid fever are shown by the following table:

	Rates per 100,000.	
Year.	*Morbidity.*	*Mortality.*
1906	674.4	73.8
1907	460.8	60.6
1908	234.4	35.7
1909	153.5	21.8
1910	112.7	17.4
1911	87.6	14.1

Thus, Philadelphia has reduced this scourge, and for 1911, when it ranked third in population, its typhoid rate placed it fourth for the lowest mortality rate for cities over 500,000 population, and in that class it was surpassed only by Boston, Chicago, and New York, in order named, with mortality rates of 9.14, 10.8, and 10.9 per 100,000.

While marked reduction in typhoid fever rates follow in all cases where that disease has been water borne, there also occurs a reduction in the total mortality rate of cities which improve their water supplies which cannot be accounted by the reduction in typhoid. I am under the impression that this fact was first pointed out by Professor Sedgwick. It was called to my attention by Mr. Nicholas Hill, of New York, who suggested that the mortality statistics of Philadelphia should be closely studied in this respect, since the concurrent reduction was, in all probability, not due to coincidence of other beneficial factors. It can be said at this time that the general reduction has every indication for prevailing in Philadelphia, in this, the first year of filtration of the entire supply. Should the indicated rates obtain for the full year, there will be about 2000 less deaths in Philadelphia in 1912 than occurred in 1911. More complete analysis than has been possible up to this time may show that in ascribing the benefits due to the improved water supply we should not overlook advancements in the public health, other than reductions in typhoid fever.

PAPER NO. 1114.

THE SIGNIFICANCE OF "THE MIDDLE THIRD."

JOHN C. TRAUTWINE, JR.
(Active Member.)

Read May 18, 1912.

IN his "Applied Mechanics," page 227, Professor Rankine says: "A structure of masonry or brickwork, requiring, as it does, to possess stability while the mortar is fresh, ought to be designed on the supposition that the joints have no appreciable tenacity." In other words, the stresses should be calculated as for a "dry" structure.

In his "Civil Engineering," page 378, Professor Rankine says: "The proper rule for limiting the deviation of the center of resistance of a rock foundation from the center of gravity of its figure is, that there should be no tension at any point of the base."

The question seems to arise: "What difference can it make whether or not there is tension, in cases where the tensile strength is neglected?"

In such a joint, an opening, on what is called the "tension" side, cannot be due to tension, of which there is none; but must be due to a failure of the material, on the *other* side of the joint, to resist *compression;* and herein, as I believe, lies the real significance of "the middle third."

In Fig. A let the upper block be uniformly loaded with vertical rods of equal length, so that the load is equally distributed over a b, as shown. Then the resultant, R, is at the center, o, of the joint.

Let R = the resultant, L = the length of a b, and width = unity. Then the unit pressure, $p = R/L$. In Fig. A, also, the *maximum* unit pressure, p_a, at a, = p.

In Fig. B we suppose the block so loaded that the unit pressure, beginning with $p_a = 2p$, at a, diminishes uniformly to $p_b = 0$, at b. The ordinates, representing the unit pressures, thus form a triangle, and we know that their resultant, R, passes through the gravity center of this triangle, or *at the end of the middle third* of the block, viz.: at a point distant $x = L/6$ from the center, o, of the block, or at a distance, $y = L/3$, from that end, a, which is nearest to the resultant.

Fig. C shows that the distribution of pressures, in Fig. B, after the shifting of R to a distance, x, = $\frac{L}{6}$, from center, is the same as it would be if we were to add, to the rectangle of Fig. A, a *couple*, represented by the two triangles of Fig. C, the left-hand triangle representing *added* pressures, while the right-hand triangle represents *diminutions* of pressure.

The couple is composed of (1) a downward force, F, distributed over the left half of a b, and (2) an upward force, − F, similarly distributed over the right half of a b. Their distance apart (the leverage of the couple) is the distance between the gravity centers of the two triangles, = $\frac{2}{3}$ L. Hence, the moment of the resisting couple is F $\frac{2}{3}$ L.

To find the values of these triangles, we have, for equilibrium of moments:

$$R\,x = F\,\tfrac{2}{3}\,L;$$

Hence,

$$F = \frac{R\,x}{\frac{2}{3}\,L} = \tfrac{3}{2}\,p\,x.$$

The *mean* additional unit pressure, under the left-hand triangle, is

$$\frac{F}{L/2} = \tfrac{3}{2}\,p\,x.\,\frac{2}{L} = \frac{3\,x}{L}\,p.$$

The *maximum* additional unit pressure, at a, is twice this, or f = $\frac{6\,x}{L}$ p, and the *total* unit pressure, p_a, at a, is

$$p_a = p + f = p + \frac{6\,x}{L}.\,p = p\left(1 + \frac{6\,x}{L}\right).$$

At b, we have:

$$p_b = p - f = p - \frac{6\,x}{L}.\,p = p\left(1 - \frac{6\,x}{L}\right).$$

In Figs. B and C, x = $\frac{L}{6}$, or 6 x = L; so that:

$$p_a = \left(1 + \frac{L}{L}\right)p = 2\,p$$

$$\text{and } p_b = \left(1 - \frac{L}{L}\right)p = 0$$

Thus far, the distance, x, of the resultant, R, from the center, o, of the joint, has not exceeded $\frac{L}{6}$. In other words, the resultant has not passed beyond the middle third, and there could be no tension in any part of the joint, even if the material were capable of sustaining tension.

Under these circumstances it is immaterial whether or not the material can sustain tension.

But we now pass to cases where x is *greater* than L / 6; *i. e.*, where the resultant falls *beyond* the middle third.

In such cases (Figs. D and E) the conditions are profoundly affected by the ability or the inability of the joint to sustain tension.

Let Fig. D represent a case where the material *can* sustain tension, the line, *a b*, representing, not a masonry joint, but an imaginary plane in a solid steel block, and let us examine the stresses in that plane.

Let R be applied at a point distant only y = L / 6 from the end, a, of the block.

In this case, $x = \frac{L}{3}$; $\frac{6x}{L} = \frac{6L}{3L} = 2$; and $p_a = p\left(1 + \frac{6x}{L}\right) = 3p$.

At b, we have tension, or negative pressure,

$$p_b = p\left(1 - \frac{6x}{L}\right) = p\left(1 - 2\right) = -p.$$

In the influence diagram, Fig. G, showing the joint, a b, enlarged, the straight lines, m n and m q, show how the total unit pressures, at a and at b, respectively, vary as the resultant is shifted, from the center, o, to and beyond * either edge, as a, of the joint; the ordinates to the line m n representing the unit pressures, p_a, at a, while those to the line m q represent the unit pressures or tensions, p_b, at b; both for a joint capable of sustaining tension.

It will be noted especially that, when the tension is brought into play (the entire joint being in action), the total unit pressures and tensions, at each end of the surface, increase *proportionally with the distance, x,* of the resultant, *R,* from the center, *o;* as indicated by the lines m n and m q.

But when, as indicated by the supporting rollers, in Fig. E, and as in masonry joints generally, the surface is (or is supposed to be) incapable of resisting tension, and when the distance, x, of the resultant, R, from the center, o, exceeds L/6, the case is altogether different; for then *only a portion of the joint is in service.* This portion is = 3 y, where y is the distance of the resultant, R, from the nearer edge, a. The rest of the joint is idle.

Now, there being no tension, and the pressure being concentrated upon the limited surface, = 3 y, we have, for the mean pressure upon 3 y,

$$\text{mean unit pressure} = \frac{R}{3y};$$

* Fig. F shows that, where the surface can sustain tension, the resultant of the forces acting upon the surface may fall *beyond* the edge of the surface.

and, for the maximum unit pressure, p_a, at a:

$$p_a = \frac{2\,R}{3\,y};$$

and it will at once be seen that, as the resultant, R, approaches the nearer end, a, of the surface, the maximum unit pressure, p_a, at a, increases very rapidly, and no longer in simple proportion to the distance, x, of the resultant, R, from the center, o, of the joint, as it did (1) when R fell within the middle third, or (2) when the tension is active.

In cases like Fig. E, the maximum unit pressure, a, soon becomes enormous, and it would reach infinity if the resultant, R, however small, could actually be applied at the very edge, a.

All this is indicated by the curved line, s t, Fig. G.

Conversely, the same fact may be stated by saying that, for a given permissible unit pressure, the resultant may approach the edge of the surface more closely when there is tension than when there is none.

Thus (Fig. G) if the max. unit pressure, p_a, must not exceed 4 p, the resultant, R, may be applied at the edge, a, if there is tension, but must be kept back from *a* a distance = L/6 when there is no tension.

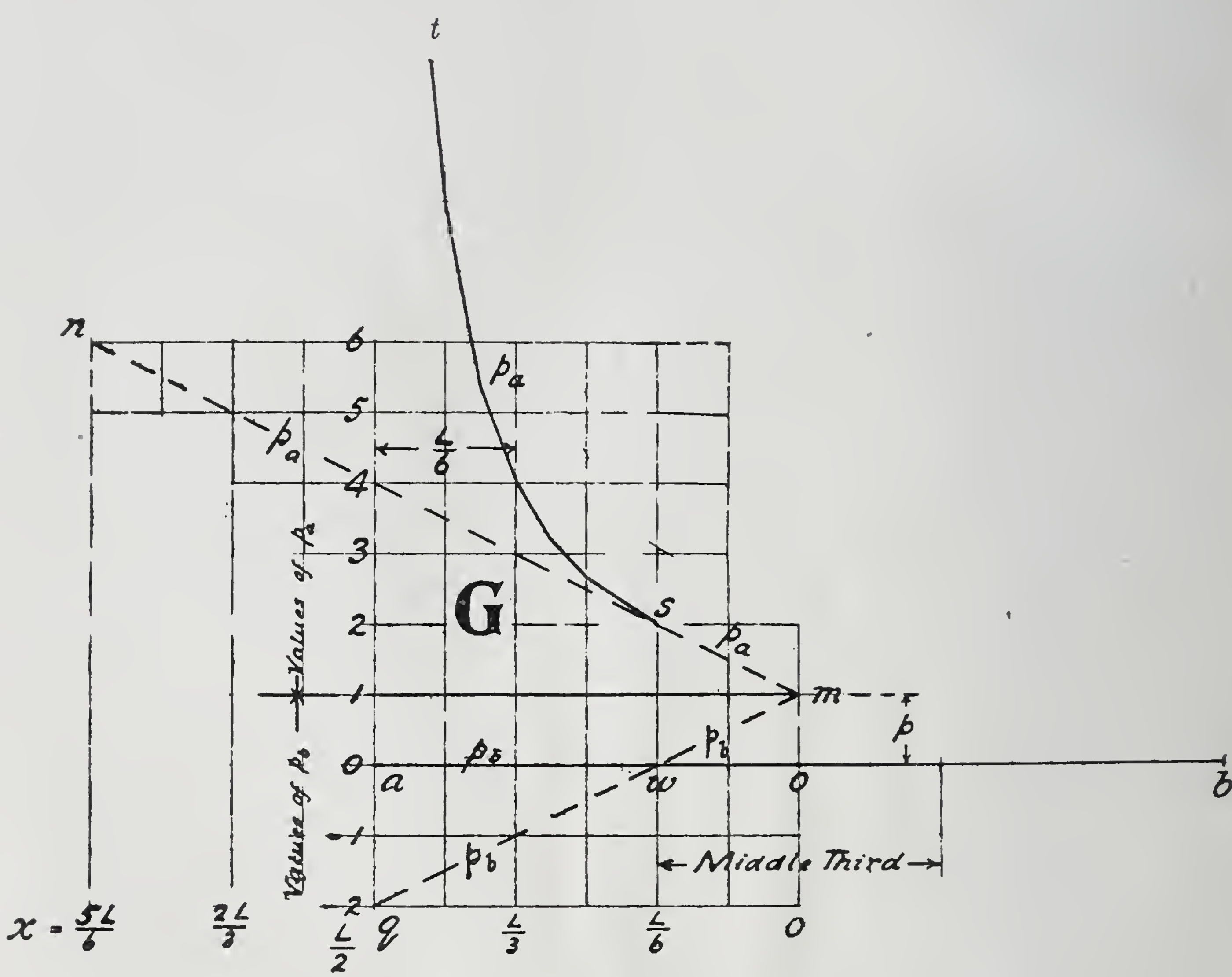
The broken line, m w a, Fig. G, shows the pressures at the other end, b, of the joint, when there is no tension; the pressure, p_b, there diminishing from p_b = p, when R is at the center, o (x = zero), to p_b = zero when x = L/6, and remaining p_b = zero thereafter.

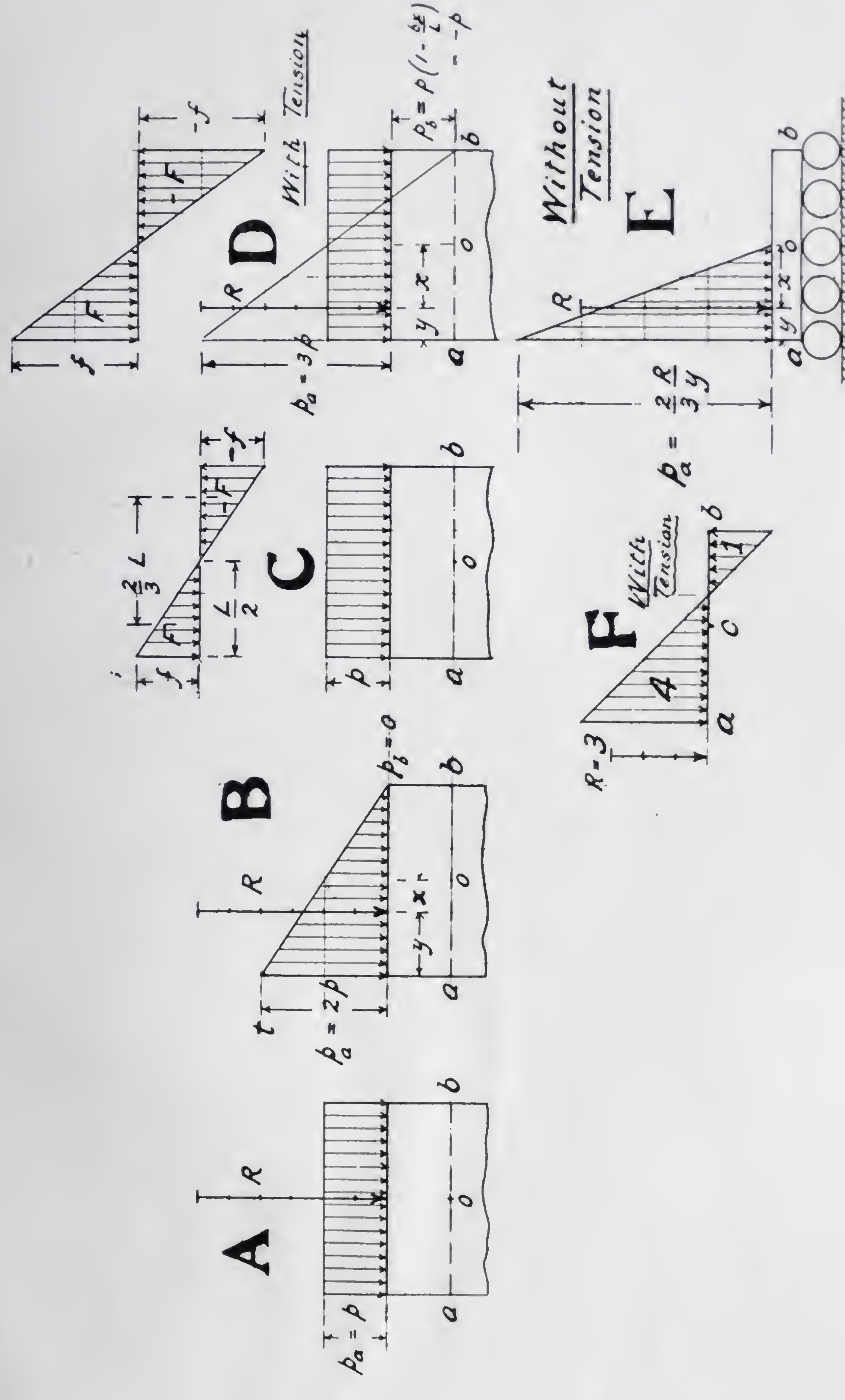
The influence diagram, Fig. G, gives values of p_a and p_b, as follows:

	x	y	p_a/p		p_b/p	
			With Tension	Without Tension	With Tension	Without Tension
Within Middle Third	0	L/2	1	1	1	1
	L/12	5L/12	1.5	1.5	0.5	0.5
	L/6	L/3	2	2	0	0
Beyond Middle Third	L/4	L/4	2.5	2 2/3	−0.5	0
	L/3	L/6	3	4	−1	0
	5L/12	L/12	3.5	8	−1.5	0
	L/2	0	4	∞	−2	0
	7L/12	−L/12	4.5	..	−2.5	..
	2L/3	−L/6	5	..	−3	..
	9L/12	−L/4	5.5	..	−3.5	..
	5L/6	−L/3	6	..	−4	..

It thus appears that, for *any given resultant*, *R*, applied at *any given distance*, *x*, from the center, o, of the joint, exceeding L/6, the *greater* maximum unit load, p_a, obtains when the material of the joint is *incapable* of sustaining tension.

It would appear also that, when Professor Rankine said: "there should be no tension at any point of the base," what he really meant to say was that, when the material is *incapable* of sustaining tension, the passing of the resultant beyond the middle third brings dangerous and rapidly increasing *compressive* stresses upon the *compression* side of the joint, and these (by *crushing* the material there) may cause the "tension" side of the joint to open.





A
B
C
D
E
F
With Tension
Without Tension
With Tension

ABSTRACT OF MINUTES OF THE CLUB.

Business Meeting, September 21, 1912.—The meeting was called to order by Vice-President Plack at 8.35 p. m., with 70 members and visitors in attendance. The minutes of the Business Meeting of June 1st were read and approved.

The Committee on Nominations named by the Board of Directors at the meeting of June 1st was submitted to the Club and approved.

It was moved and carried that in the future smoking be abolished in the Club meetings.

Mr. George S. Bliss, Director of the Climatological Service of Pennsylvania, presented the paper of the evening, entitled, "The Importance of Meteorological Data in Engineering," which was discussed by Mr. John C. Trautwine, Jr., Mr. George S. Cheyney, Jr., Mr. John E. Codman, Dr. Henry Leffmann, Mr. H. H. Quimby, and others.

Upon motion, a vote of thanks was extended Mr. Bliss.

ABSTRACT OF MINUTES OF THE BOARD OF DIRECTORS.

Special Meeting, July 11, 1912.—Present: President Hess, Vice-Presidents Plack and Mebus, Directors Halstead, Gilpin, Vogleson, Swaab, and the Secretary in attendance.

The Secretary presented a statement of the financial condition of the Club, which showed a gain in the Income and Expense Account for the first six months of $247.79.

The Finance, Membership, Publication, Library, Meetings, and House Committees presented reports, which were approved.

The Publicity, Public Relations, and Increase of Membership Committees presented no reports, and the Secretary was asked to communicate with the Chairmen of these Committees, asking them to forward a report to the Board of Directors.

The Business Manager's report was read and approved.

The following gentlemen were elected to membership in the Club:

Active: Charles E. Bonine, Harold E. Brunner, Bruce Ford, William J. Hagman, James S. Kunkle, Otto W. Schaum, Herbert L. Towle, M. J. Turnbull, Wm. D. Uhler, A. C. Vauclain, and John E. Zimmermann.

Associate: Charles K. Brown.

Junior: E. B. Callow, Lorenzo S. Cope, James E. Diamond, Fletcher Schaum, and Harry Wickland.

The resignations of Messrs. R. W. Shelmire and E. M. Bassett were read and accepted.

It was decided that the Club officers and officials be asked to submit a statement as to the duties of their offices, to be discussed at the next meeting of the Board.

It was decided to create a special Committee on By-Laws, this Committee to consider suggestions and make studies for the improvement of the By-Laws. The President named the following members to serve on this Committee: S. M. Swaab, Chairman, Charles F. Mebus, Vice-Chairman, J. C. Trautwine, Jr., Edwin F. Smith, Carl Hering, and H. A. Moore.

The President appointed the following standing committees, those in parentheses being new members:

Finance: J. A. Vogleson, David Halstead, (E. J. Kerrick), J. M. Dodge, (S. E. Fairchild, Jr.).

House: F. K. Worley, W. L. Plack, (Richard Gilpin), (G. F. Pawling), H. A. Moore.

Meetings: S. M. Swaab, H. C. Berry, (B. A. Haldeman), Wm. Easby, Jr., J. E. Gibson.

Membership: Chas. Hewitt, F. H. Stier, (David Halstead), Robert T. Mickle, W. P. Dallett.

Publication: Chas. F. Mebus, St. George H. Cooke, (S. M. Swaab), (Wm. Easby, Jr.), (M. E. Hibbs).

Library: B. A. Haldeman, Richard Gilpin, (H. C. Berry), F. N. Morton, M. E. Hibbs.

Publicity: R. G. Develin, E. J. Kerrick, (J. A. Vogleson), F. T. Gucker, G. W. Hyde.

Advertising: D. R. Yarnall, (R. G. Develin), (Chas. F. Mebus), H. Goodwin, Jr., H. B. Allen.

The President appointed the following members to constitute the Lantern Committee: B. A. Haldeman, Chairman, E. J. Dauner, H. E. Ehlers, A. D. Morris, Chas. E. Bonine.

Regular Meeting, September 19, 1912.—Present: President Hess, Vice-President Plack, Directors Halstead, Kerrick, Worley, Develin, Berry, Haldeman, Swaab, Yarnall, Vogleson, the Secretary, and the Treasurer.

The Treasurer reported a net gain to September 1st of $862.39.

Reports from the following Committees were read and approved: Finance, Membership, Publication, Library, Meetings, Publicity, Advertising, House, Public Relations, and Increase of Membership. The Business Manager's report was presented and approved.

The following were elected to membership in the Club: Active, Charles Wirt, H. P. Gant; Associate, George Kendall Myers; Junior, Herbert Ruff.

The following Juniors were transferred to either Active or Associate membership, as follows: Active, H. H. Hewitt; Associate, William Oram and W. J. Taggart.

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